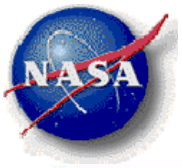


# Space Fission Power and Propulsion

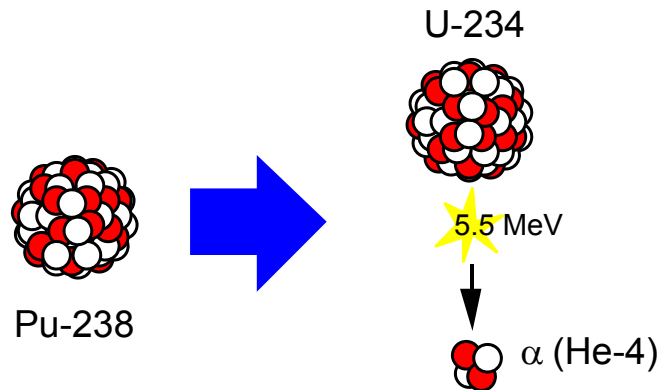


*presented by*

**Michael G. Houts, PhD**  
**[Michael.houts@nasa.gov](mailto:Michael.houts@nasa.gov)**



# Basics of Nuclear Systems



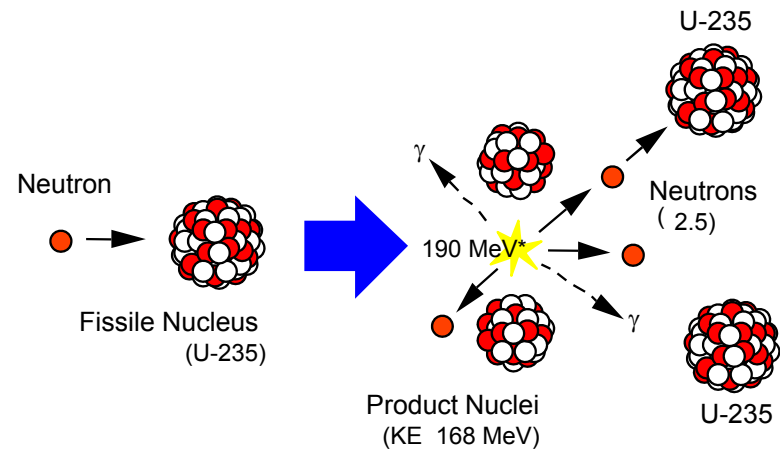
*Heat Energy = 0.023 MeV/nucleon (0.558 W/g Pu-238)*  
*Natural decay rate (87.7-year half-life)*

Long history of use on Apollo and space science missions

44 RTGs and hundreds of RHUs launched by U.S. during past 4 decades

Heat produced from natural alpha ( $\alpha$ ) particle decay of Plutonium (Pu-238)

Used for both thermal management and electricity production



*Heat Energy = 0.851 MeV/nucleon*  
*Controllable reaction rate (variable power levels)*

Used terrestrially for over 70 years

Fissioning 1 kg of uranium yields as much energy as burning 2,700,000 kg of coal

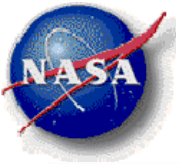
One US space reactor (SNAP-10A) flown (1965)

Former U.S.S.R. flew 33 space reactors

Heat produced from neutron-induced splitting of a nucleus (e.g. U-235)

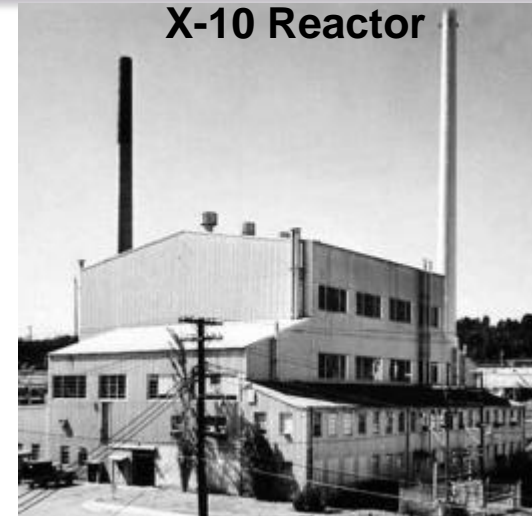
At steady-state, 1 of the 2 to 3 neutrons released in the reaction causes a subsequent fission in a "chain reaction" process

Heat converted to electricity, or used directly to heat a propellant



# Fission Introduction

- **Creating a fission chain reaction is conceptually simple**
  - Requires right materials in right geometry
- **Good engineering needed to create safe, affordable, useful fission systems**
- **1938 *Fission Discovered***
- **1939 *Einstein letter to Roosevelt***
- **1942 *Manhattan project initiated***
- **1942 *First sustained fission chain reaction (CP-1)***
- **1943 *X-10 Reactor (ORNL), 3500 kWt***
- **1944 *B-Reactor (Hanford), 250,000 kWt***
- **1944-now *Thousands of reactors at various power levels***





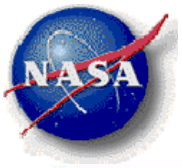


## Fission is Highly Versatile with Many Applications

- Small research reactors
  - Examples include 2000 kWt TRIGA reactor recently installed in Morocco (< \$100M)
- Advanced, high-power research reactors and associated facilities
  - Examples include the US Fast Flux Test, EBR-II, ATR, HFIR
- Commercial Light Water Reactors  
1,371,000 kWe (3,800,000 kWt)
- Space reactors
  - SNAP-10A 42 kWt / 0.6 kWe
  - Soviet reactors typically 100 kWt / 3 kWe (some systems >150 kWt)
  - Cost is design-dependent



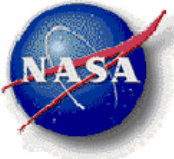
Figure II-92. SNAP 10A Flight System



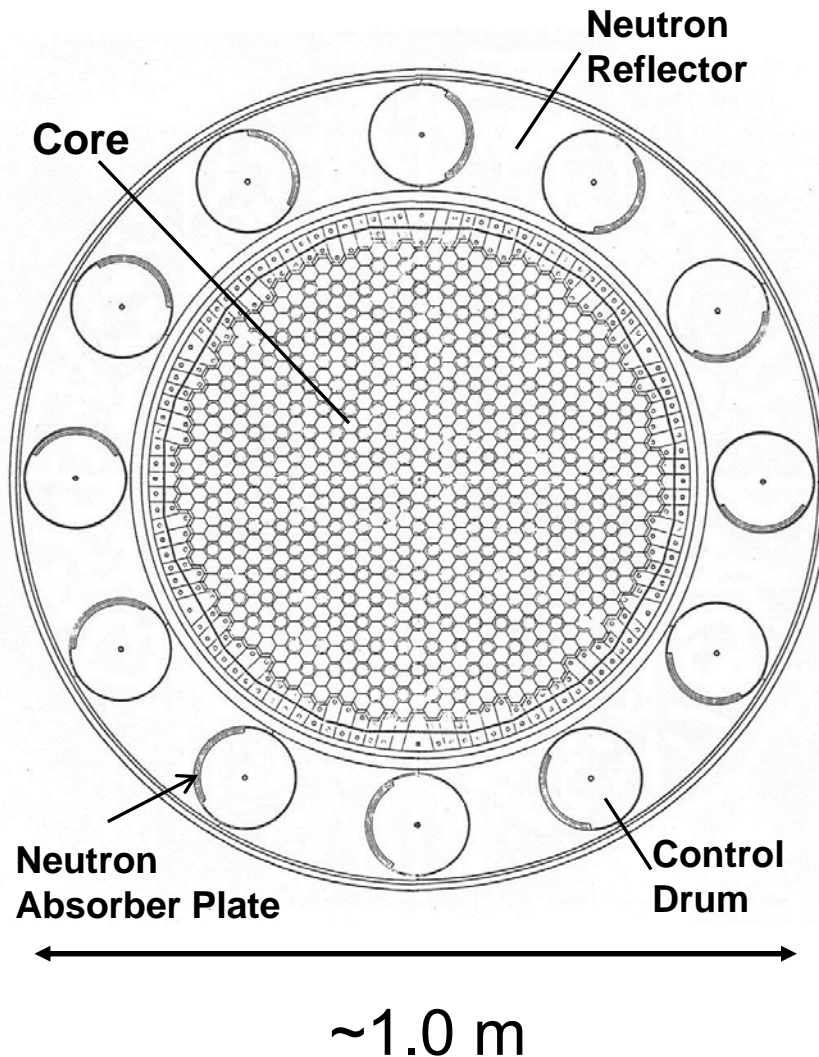
## Fission is Highly Versatile with Many Applications (continued)

- Naval Reactors
  - Hundreds of submarines and surface ships worldwide
- Production of medical and other isotopes
- Fission Surface Power
  - Safe, abundant, cost effective power on the moon or Mars
- Nuclear Thermal Propulsion
  - Potential for fast, efficient transportation throughout inner solar system
- Nuclear Electric Propulsion
  - Potential for efficient transportation throughout solar system
- Highly advanced fission systems for solar system exploration





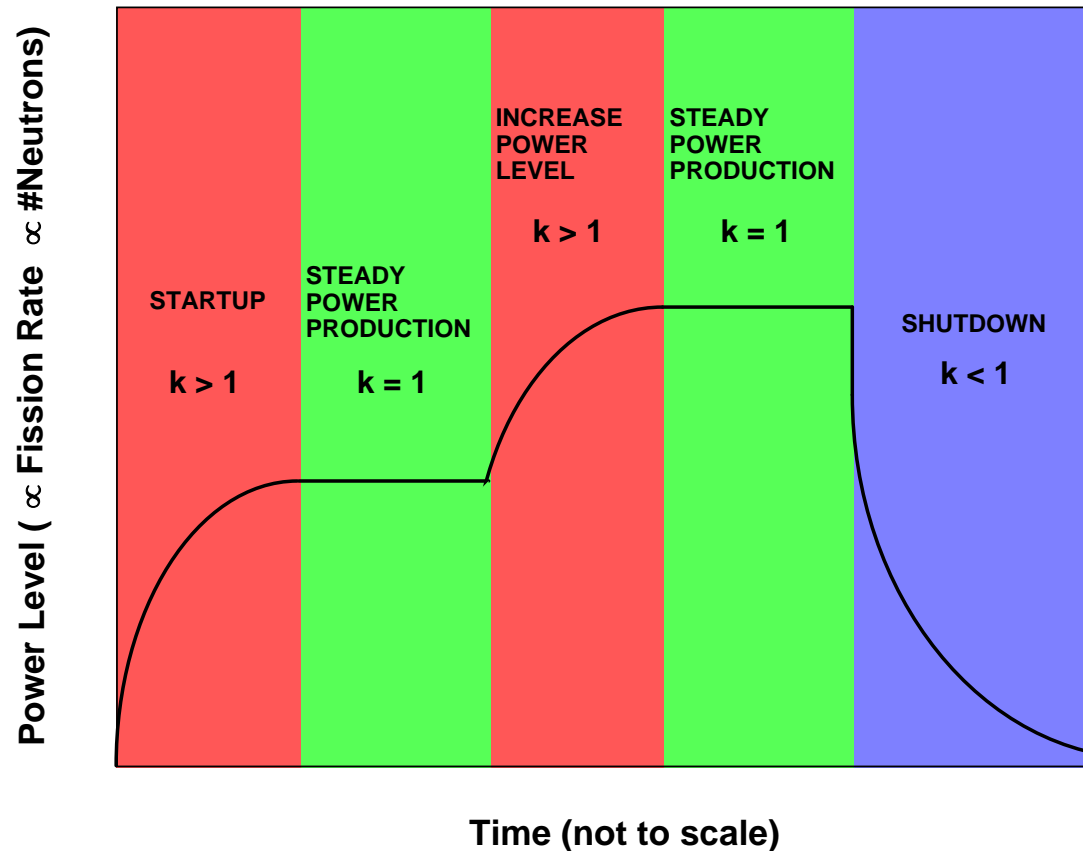
# Typical Space Fission System Operation



- System power controlled by neutron balance
- Average 2.5 neutrons produced per fission
  - Including delayed
- Constant power if 1.0 of those neutrons goes on to cause another fission
- Decreasing power if  $< 1.0$  neutron causes another fission, increasing if  $> 1.0$
- System controlled by passively and actively controlling fraction of neutrons that escape or are captured
- Natural feedback enables straightforward control, constant temperature operation
- 200 kWt system burns 1 kg uranium every 13 yrs
- 45 grams per 1000 MW-hr



# Control of Reactor Conditions

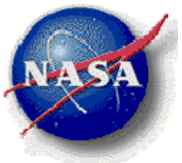


$k \equiv$  Multiplication Factor

$$= \frac{\text{Production Rate}}{\text{Loss Rate}} = \frac{N(t+l_n)}{N(t)}$$

- $< 1$  (subcritical,  $dN/dt < 0$ )
- $= 1$  (critical,  $dN/dt = 0$ )
- $> 1$  (supercritical,  $dN/dt > 0$ )





# Safe, Compact, Near-Term Fission Power Systems Could Help Enable Higher Power Fission Propulsion Systems



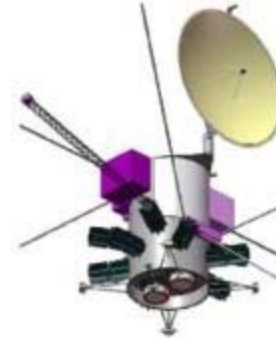
## Science:



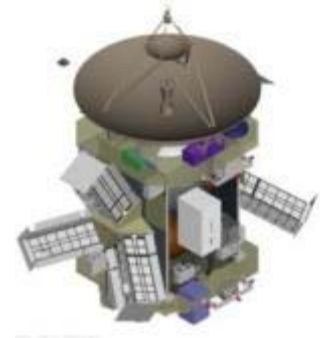
Jupiter Europa Orbiter  
~600 We (5 to 6 RPS)



Neptune Systems Explorer  
~3 kWe (9 Large RPS)



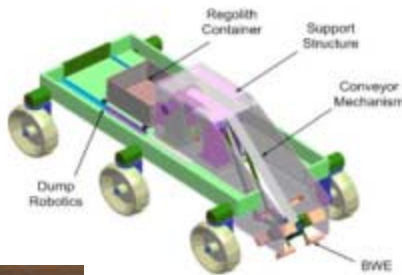
Kuiper Belt Object Orbiter  
~4 kWe (9 Large RPS)



Trojan Tour  
~800 We (6 RPS)

## Exploration:

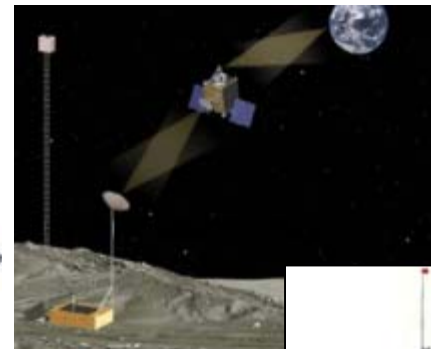
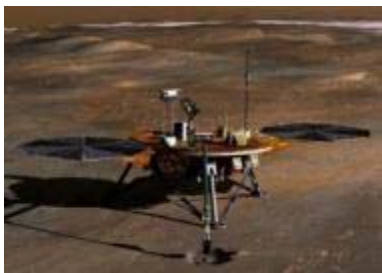
Teleoperated  
Rovers



ISRU Demo  
Plants



Site Survey  
Landers

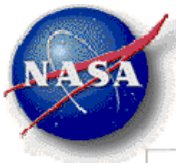


Comm Relay  
Stations

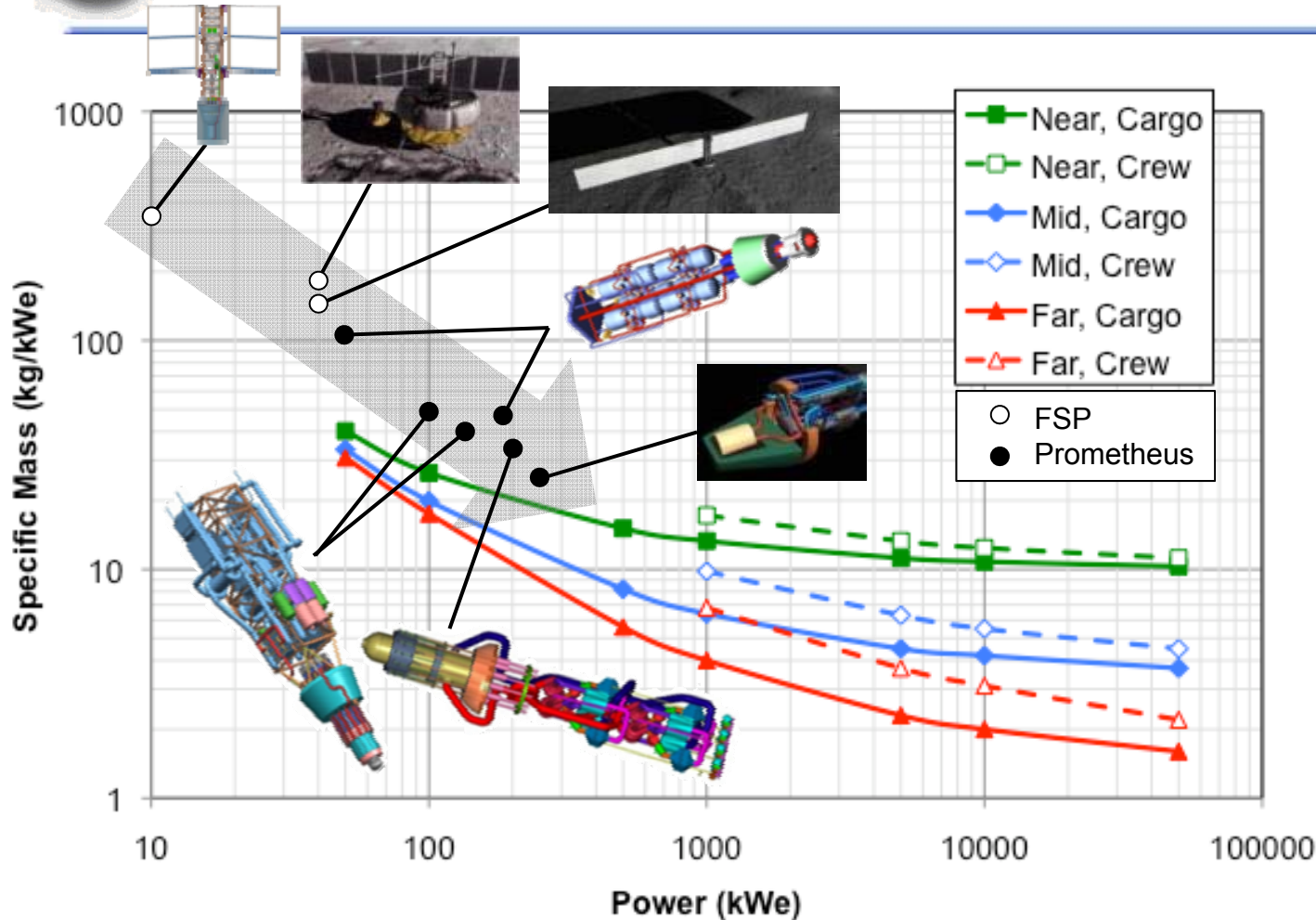
Remote Science  
Packages







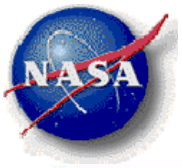
# Fission Can Provide the Energy for Either Nuclear Thermal or Nuclear Electric Propulsion Systems



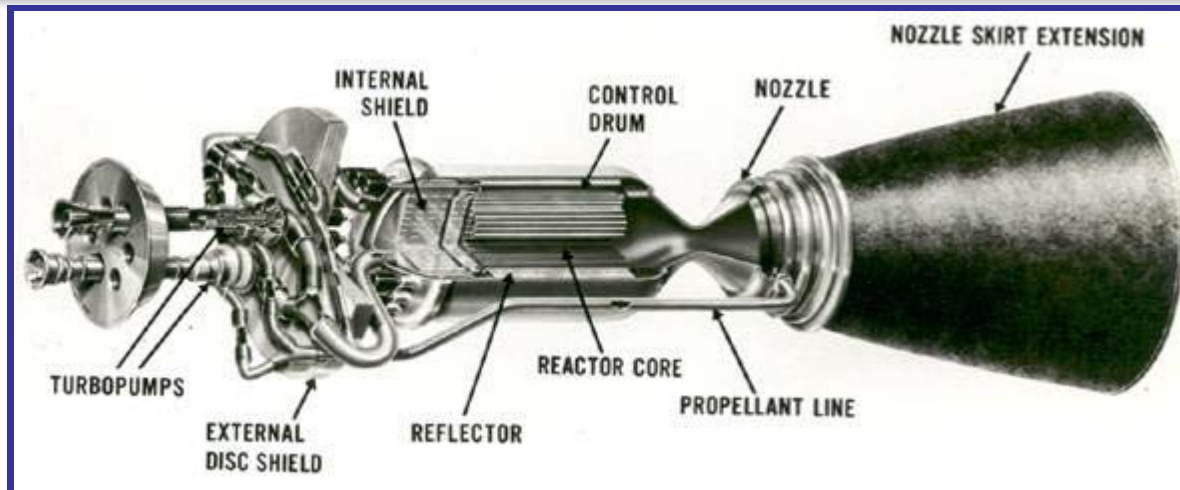
Near=Liq Metal Rx, Brayton, 1300K, 6 kg/m<sup>2</sup>, 200 Vac (Available ~10 yrs)  
 Mid=Liq Metal Rx, Brayton, 1500K, 3 kg/m<sup>2</sup>, 1000 Vac (Available ~ 15-20 yrs)  
 Far=Liq Metal Rx, Brayton, 2000K, 1.5 kg/m<sup>2</sup>, 5000 Vac (Available ~ 25-30 yrs)  
 Cargo=Instrument rated shielding,  $1.6 \times 10^{15}$  nvt,  $1.2 \times 10^8$  rad @ 2 m  
 Crew=Human rated shielding, 5 rem/yr @ 100 m, 7.5° half angle

- NEP Power System Performance Projections from 2001 STAIF Conference
- Fission Surface Power and Prometheus Concepts Superimposed

Chart courtesy  
 Lee Mason,  
 NASA GRC

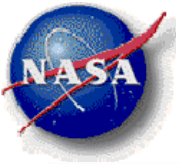


## NASA is Currently Funding an “Advanced Exploration Systems” Project Investigating Nuclear Thermal Propulsion (NTP)



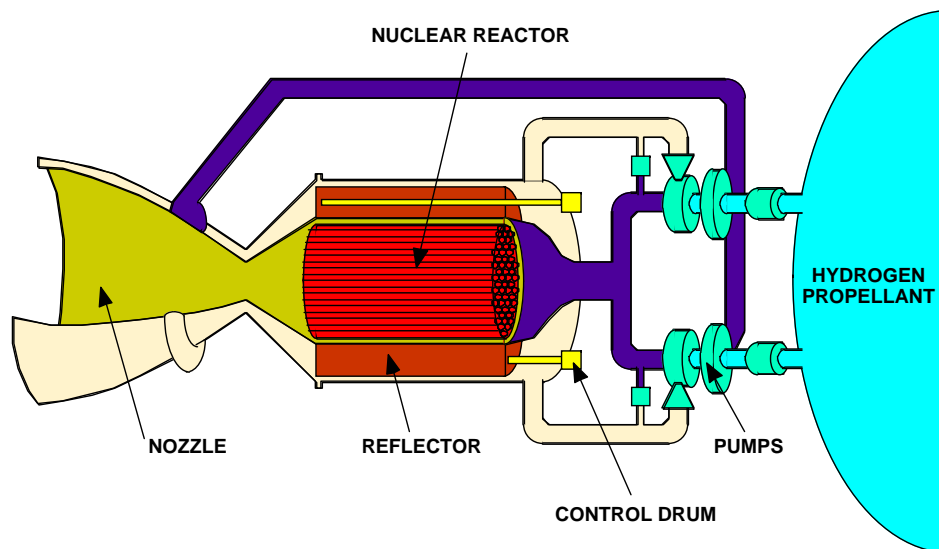
- Nuclear thermal propulsion (NTP) is a fundamentally new capability
  - Energy comes from fission, not chemical reactions
  - Virtually unlimited energy density
- Initial systems will have specific impulses roughly twice that of the best chemical systems
  - Reduced propellant (launch) requirements, reduced trip time
  - Beneficial to near-term/far-term missions currently under consideration
- Advanced nuclear propulsion systems could have extremely high performance and unique capabilities
- A first generation NTP system could serve as the “DC-3” of space nuclear power and propulsion





# How Does NTP Work?

- Propellant heated directly by a nuclear reactor and thermally expanded/accelerated through a nozzle
- Low molecular weight propellant – typically Hydrogen
- Thrust directly related to thermal power of reactor:  $50,000 \text{ N} \approx 225 \text{ MW}_{\text{th}}$  at 900 sec
- Specific Impulse directly related to exhaust temperature: 830 - 1000 sec (2300 - 3100K)
- Specific Impulse improvement over chemical rockets due to lower molecular weight of propellant (exhaust stream of O<sub>2</sub>/H<sub>2</sub> engine runs much hotter than NTP)

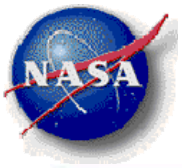


Major Elements of a Nuclear Thermal Rocket

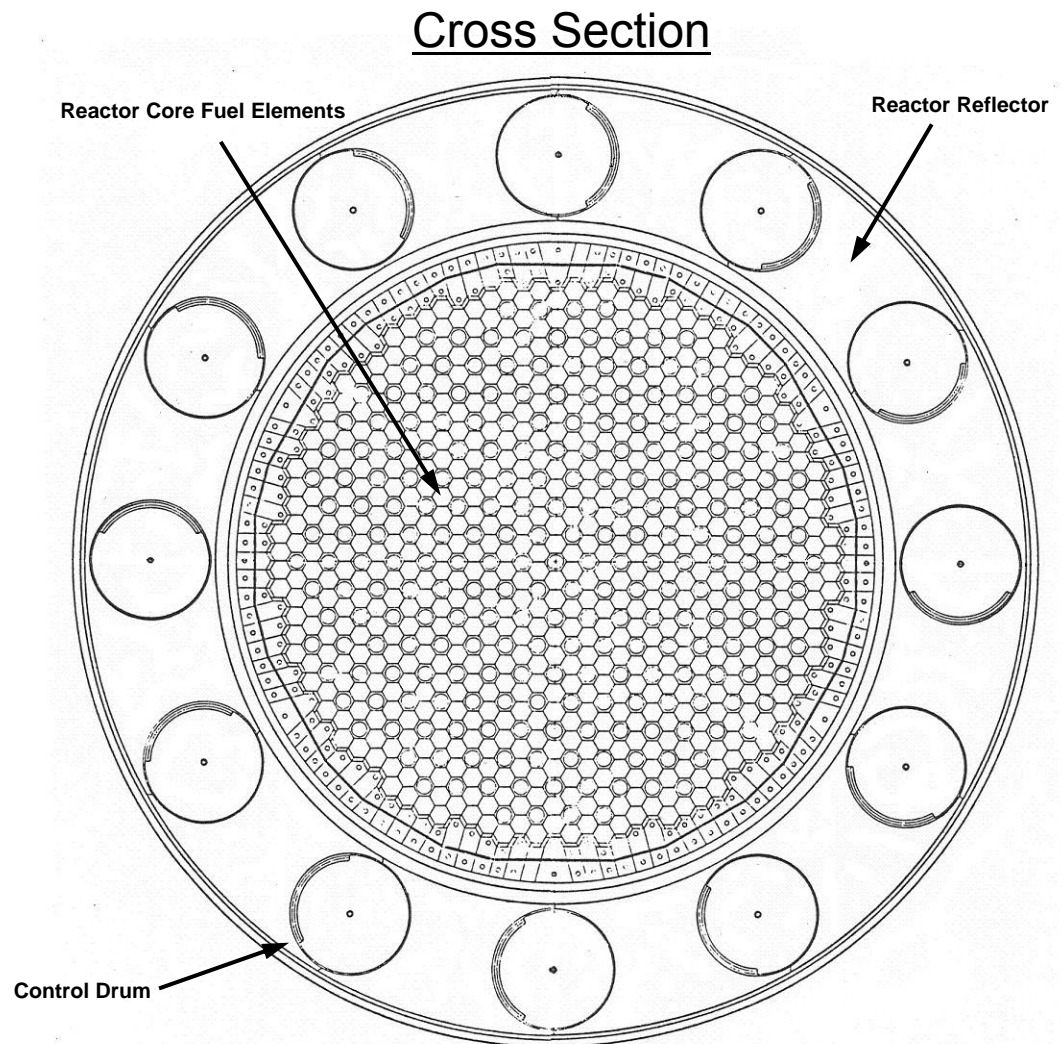
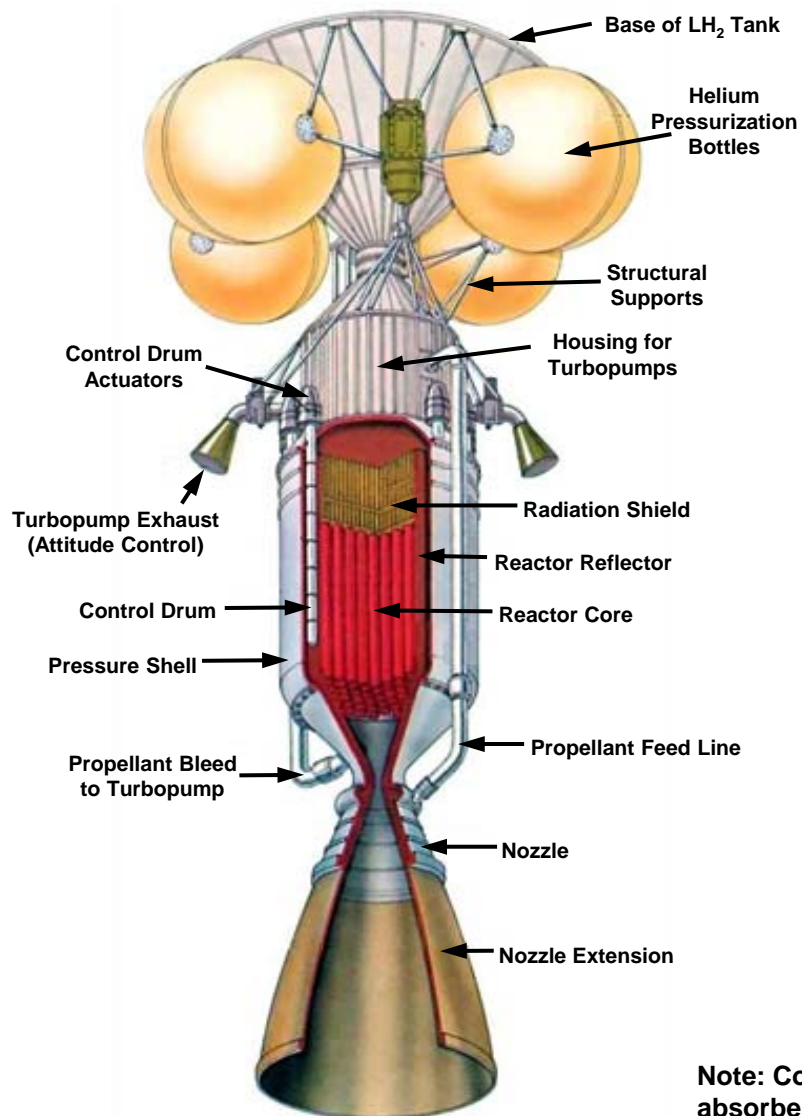


NERVA Nuclear Thermal Rocket Prototype

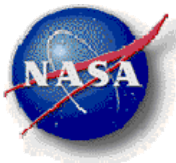




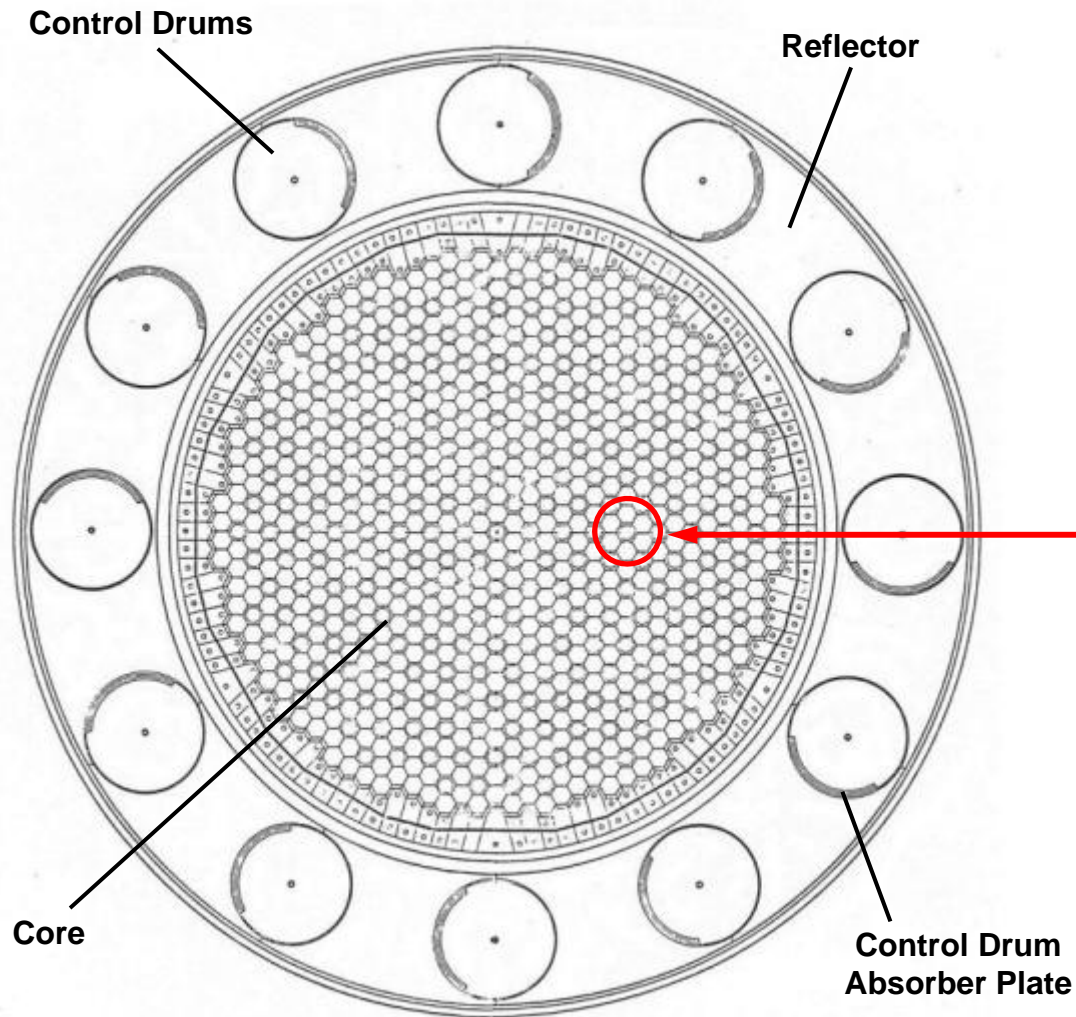
# Nuclear Engine For Rocket Vehicle Applications (NERVA)



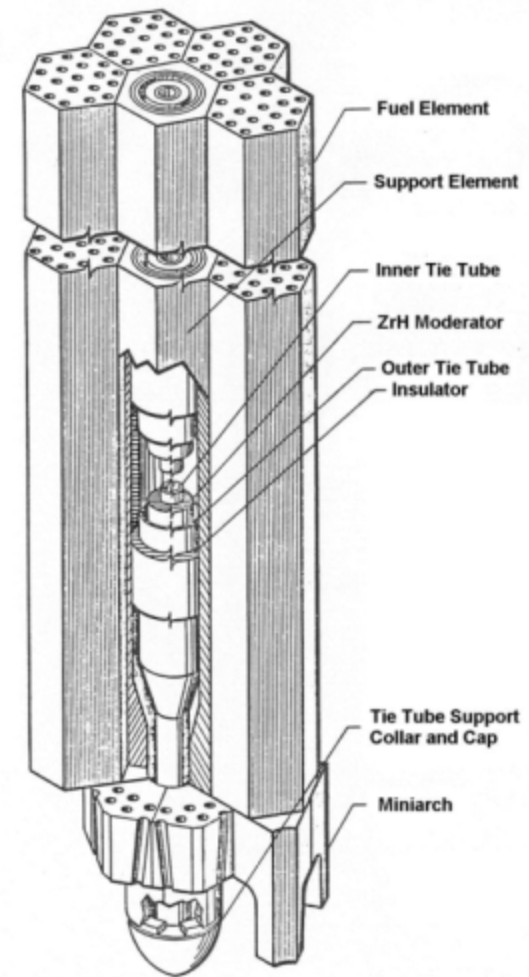
Note: Control drums rotate to control reactivity. Part of circumference covered with absorber and the rest is a reflector.



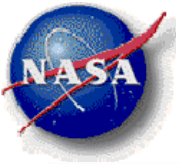
# NCPS Builds on Previous NTP Engine Designs / Tests



NERVA Reactor Cross Section



Fuel Segment Cluster



## *A Vision for NASA's Future ...*

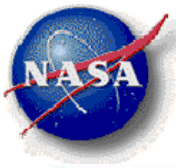
President John F. Kennedy ...

- ◆ First, I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth....
- ◆ Secondly, an additional 23 million dollars, together with 7 million dollars already available, **will accelerate development of the Rover nuclear rocket**. This gives promise of some day providing a means for even more exciting and ambitious exploration of space, perhaps beyond the Moon, perhaps to the very end of the solar system itself.

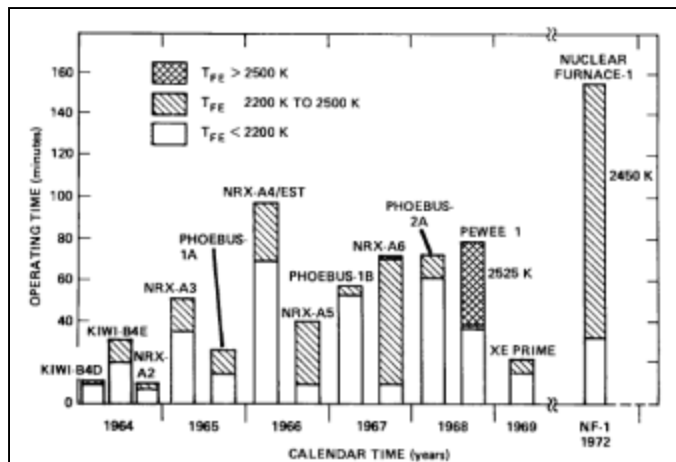
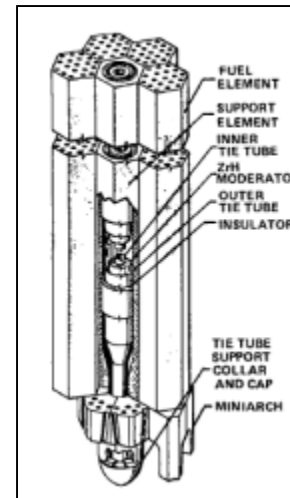
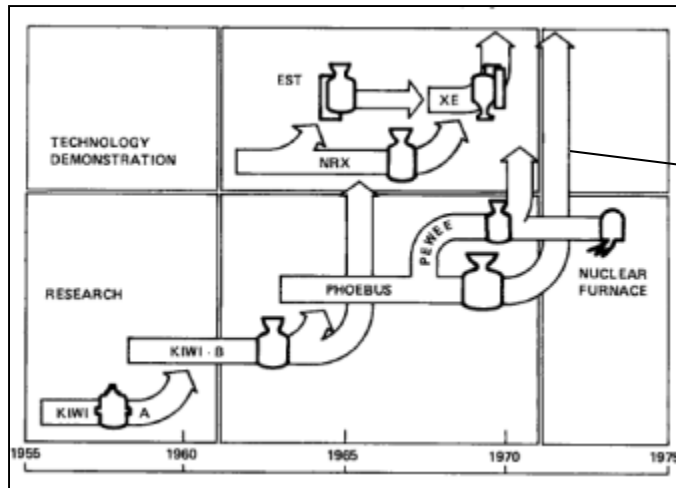


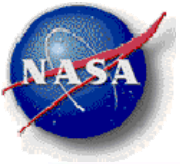
Excerpt from the 'Special Message to the Congress on Urgent National Needs'  
President John F. Kennedy  
Delivered in person before a joint session of Congress May 25, **1961**





## Leverage the highly successful Rover/NERVA program (1955-1973) and more recent programs

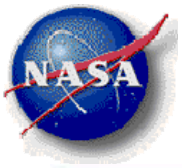




## PHOEBUS NUCLEAR ROCKET ENGINE



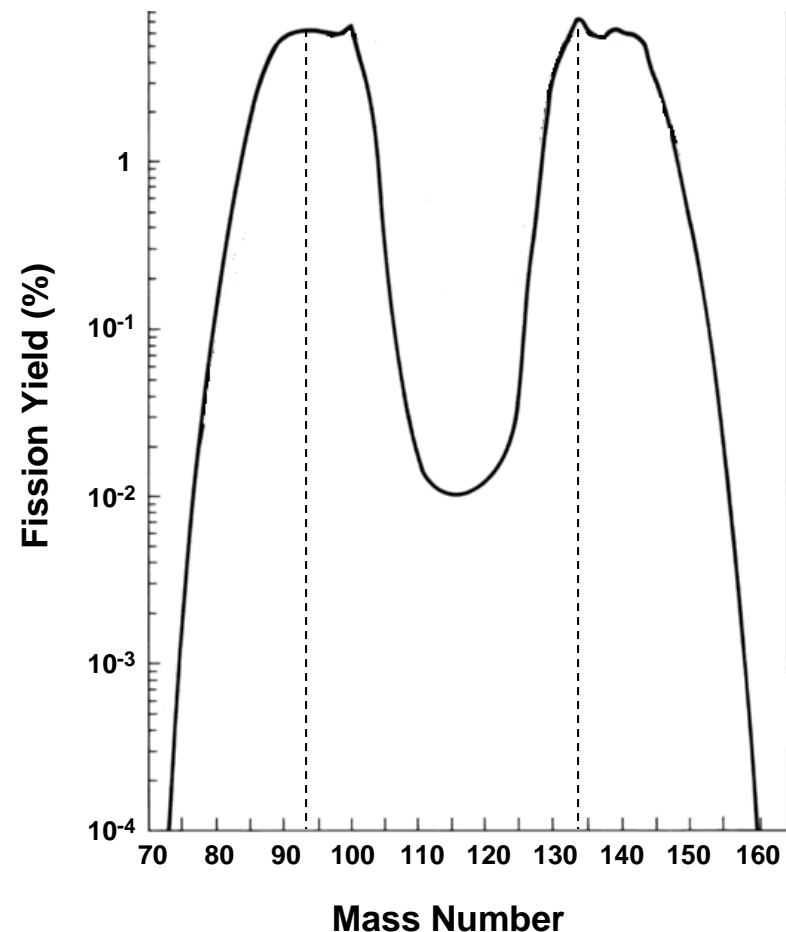
**The most powerful nuclear rocket engine ever tested (Phoebus 2a) is shown during a high-power test. The reactor operated for about 32 minutes, 12 minutes at power levels of more than 4.0 million kilowatts.**



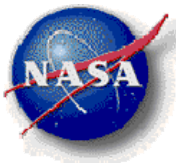
# Fission Products

- Fission events yield bimodal distribution of product elements.
- These products are generally neutron-rich isotopes and emit beta and gamma particles in radioactive decay chains.
- Most products rapidly decay to stable forms – a few, however, decay at slow rates or decay to daughter products which have long decay times.
- Example fission products of concern:
  - Strontium-90 (28.8-year half-life)
  - Cesium-137 (30.1-year half-life)
- Isotope amounts decrease by factor of 1,000 after 10 half-lives and 1,000,000 after 20 half-lives.
- Decay power 6.2% at  $t=0$  (plus fission from delayed neutrons), 1.3% at 1 hour, 0.1% at 2 months (following 5 years operation).

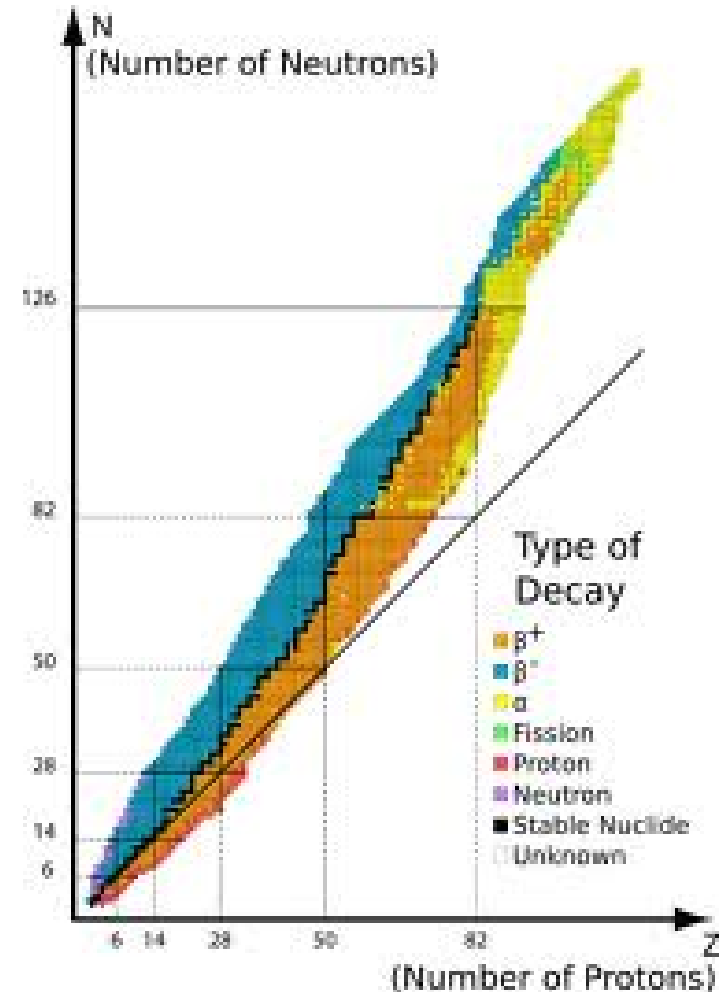
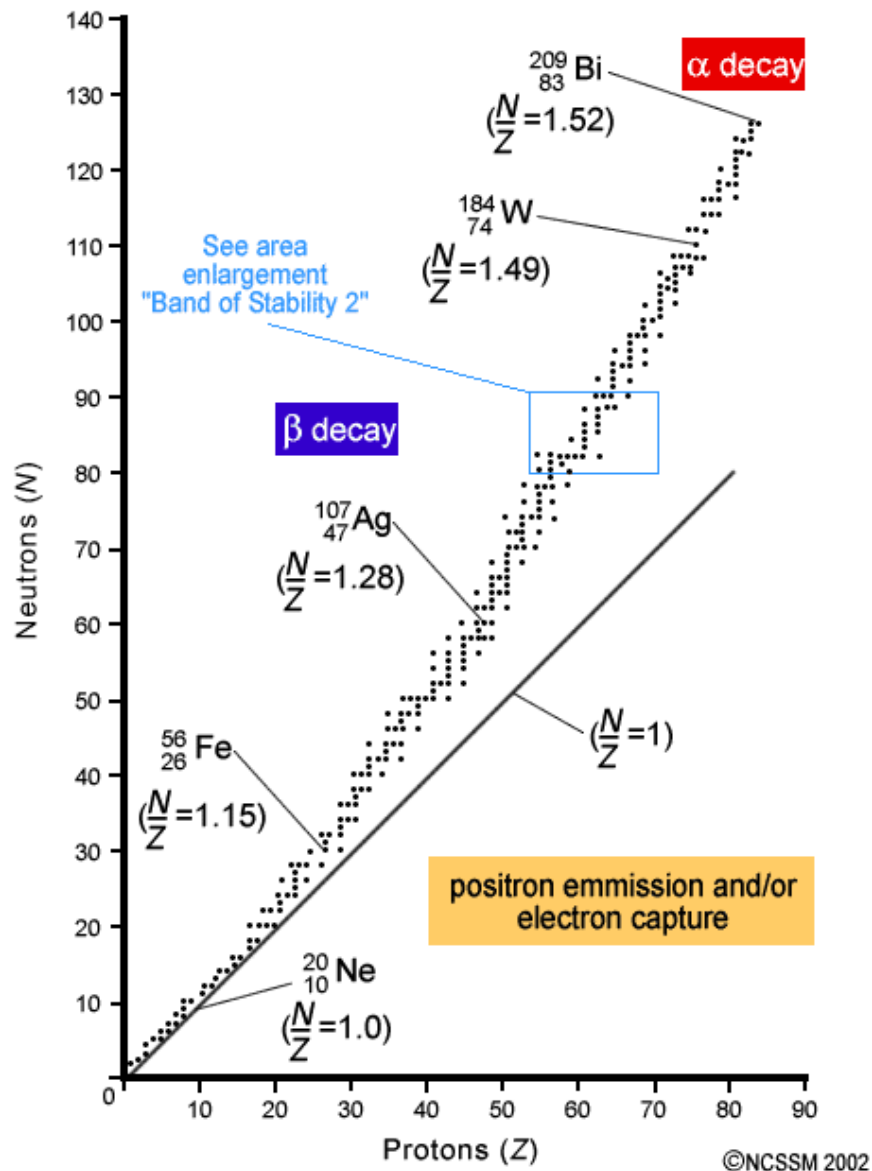
## Product Yields for Thermal Neutron (0.025 eV) Fission of U-235

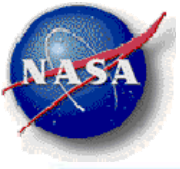






# Fission Products





# Gamma Radiation Shielding

$$I/I_0 = (B)e^{-\mu/\rho(x\rho)}$$

$I$  = intensity

$I_0$  = initial intensity

$B$  = Buildup Factor

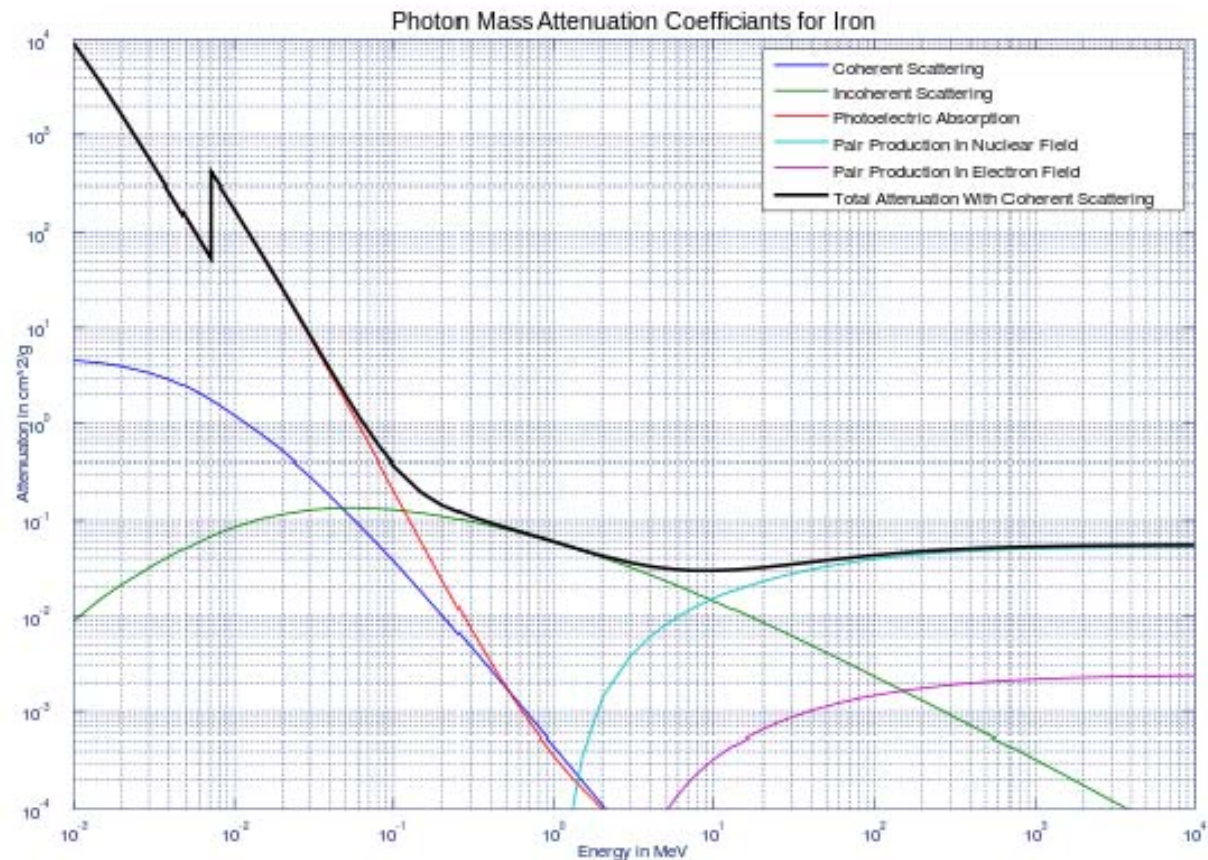
$e$  = 2.71828

$\mu$  = linear attenuation coefficient

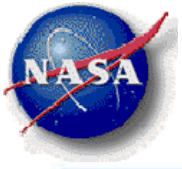
$\rho$  = density

$\mu/\rho$  = mass attenuation coefficient

$X$  = shield thickness



<http://physics.nist.gov/PhysRefData/XrayMassCoef/tab3.html>



## Mass Attenuation Coefficient ( $\mu/\rho$ cm<sup>2</sup>/g) of Al, Fe, W, and U at 1.0, 3.0, and 8.0 MeV

---

	Al	Fe	W	U
1.0 MeV	0.0615	0.0600	0.0618	0.0790
3.0 MeV	0.0354	0.0362	0.0408	0.0445
8.0 MeV	0.0244	0.0299	0.0447	0.0488

Shield design must also take into account “buildup”, inelastic neutron scatter, gammas from neutron capture, geometry, thermal management, radiation damage, and other factors.





# Neutron Radiation Shielding

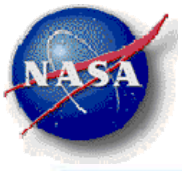
---

Use hydrogenous material to slow neutrons.

Optimal Design – Avoid Capture Gammas, Gammas From Inelastic Scatter

$^6\text{Li}$  and  $^{10}\text{B}$  capture neutrons with no significant gamma radiation released.

Water is a great neutron shield, borated water a little better still!



# Neutron Cross Sections

---

Measure of the probability of a particular neutron-nucleus interaction.

Property of the nucleus and the energy of the incident neutron.

Symbolized “ $\sigma$ ”, common unit is “barn” =  $1.0 \times 10^{-28} \text{ m}^2$

Neutron Flux =  $n v = \Phi$

$n$  = neutrons /  $\text{m}^3$

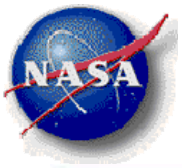
$v$  = neutron speed (m/s)

Reaction rate =  $\Phi N \sigma$

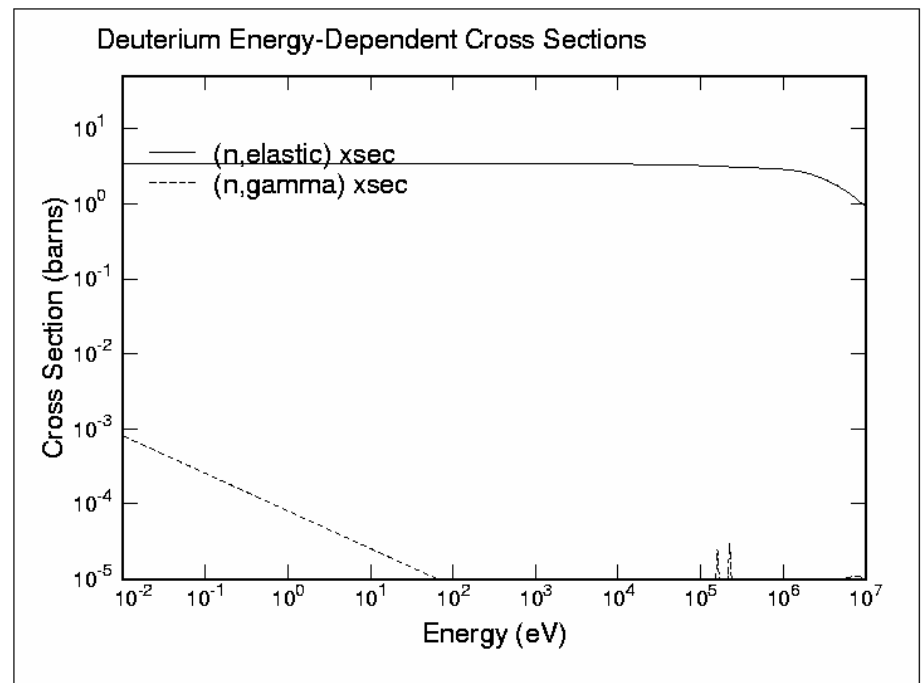
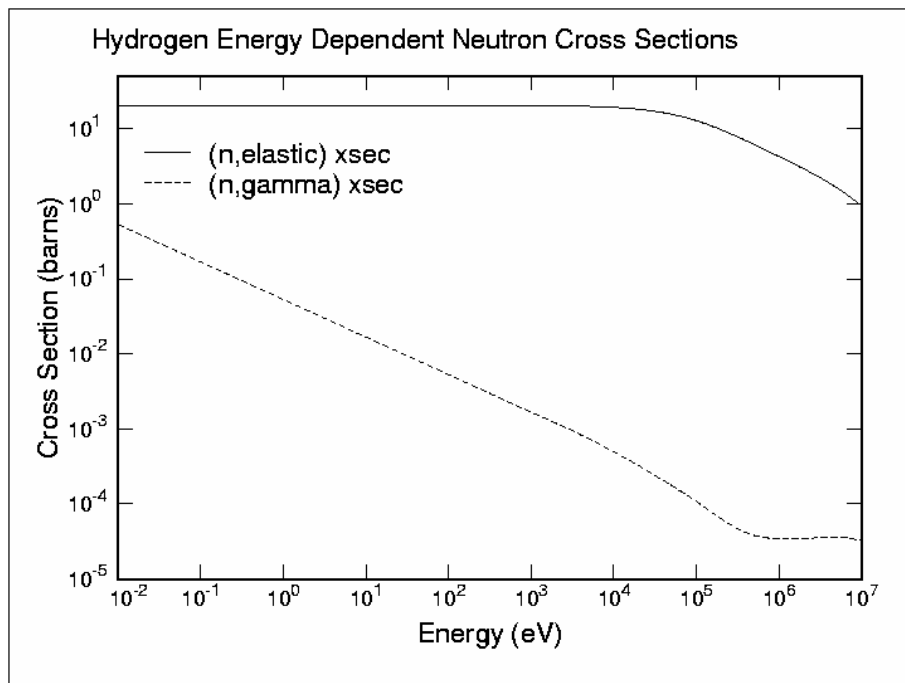
$N$  = nuclei /  $\text{m}^3$

$\Phi$  = neutron flux (neutrons /  $\text{m}^2\text{-s}$ )

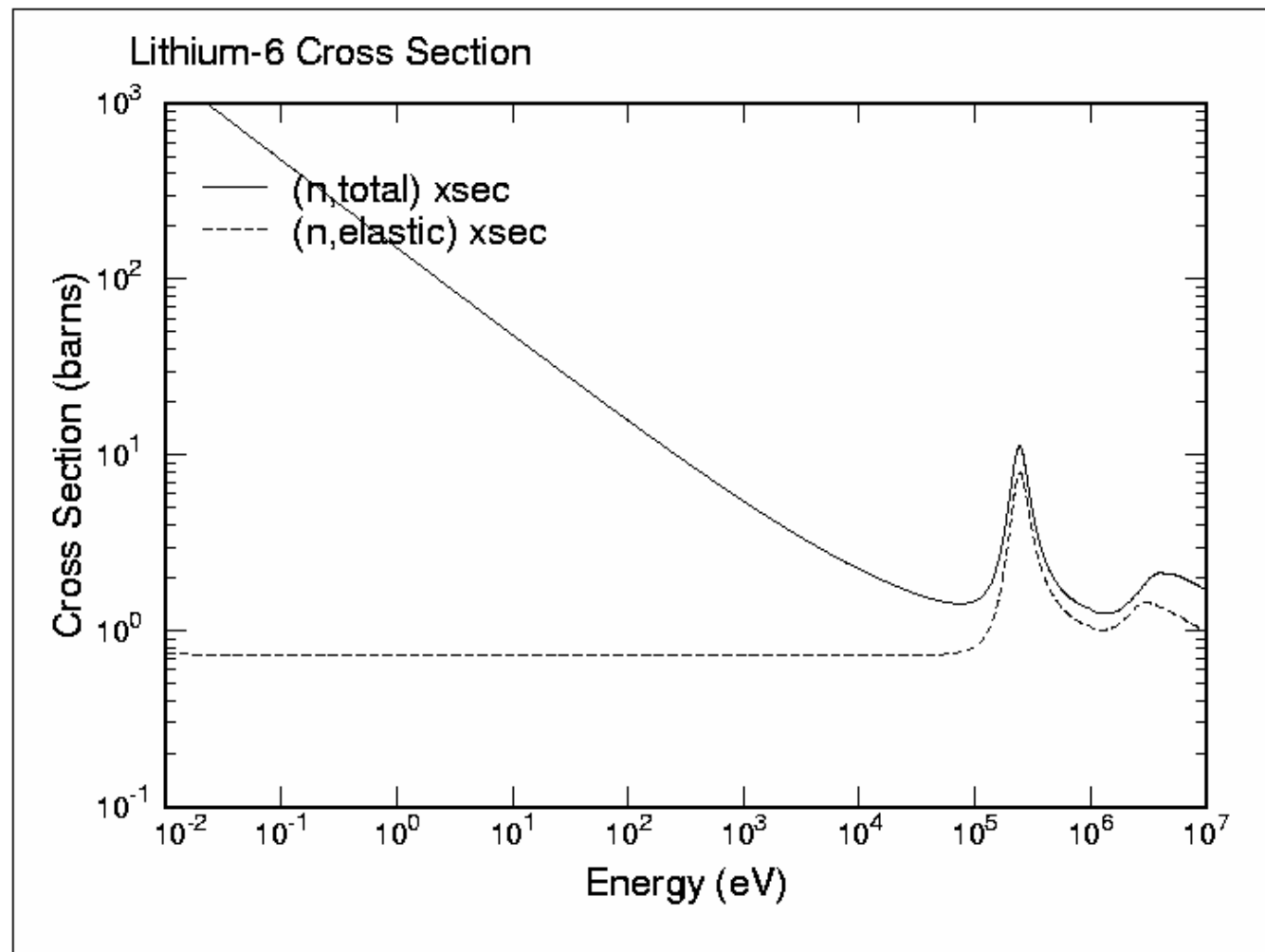
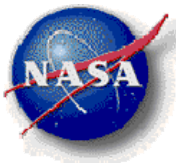
$\sigma$  = cross section ( $\text{m}^2$ )

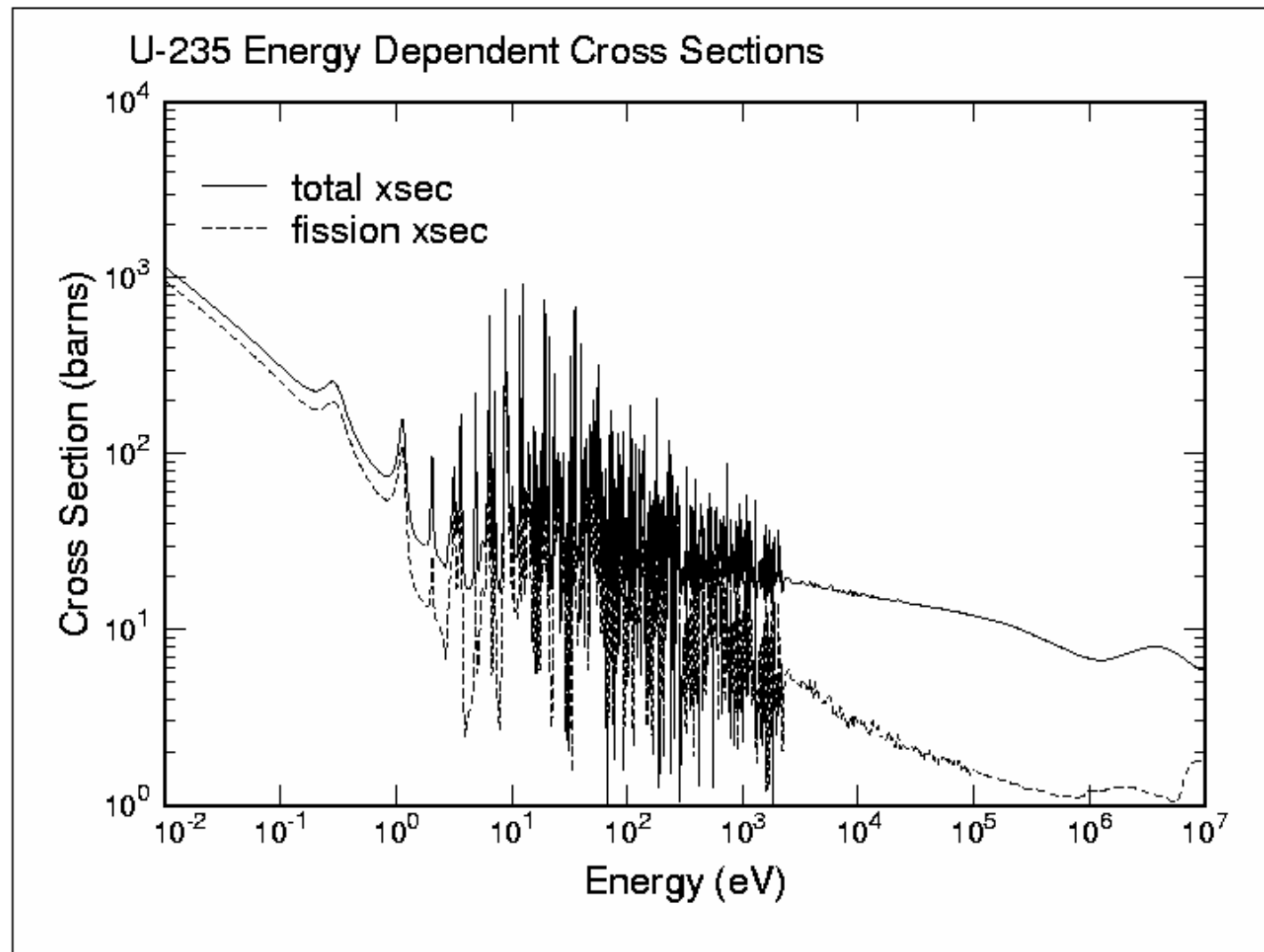
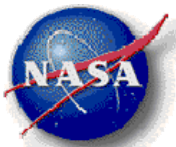


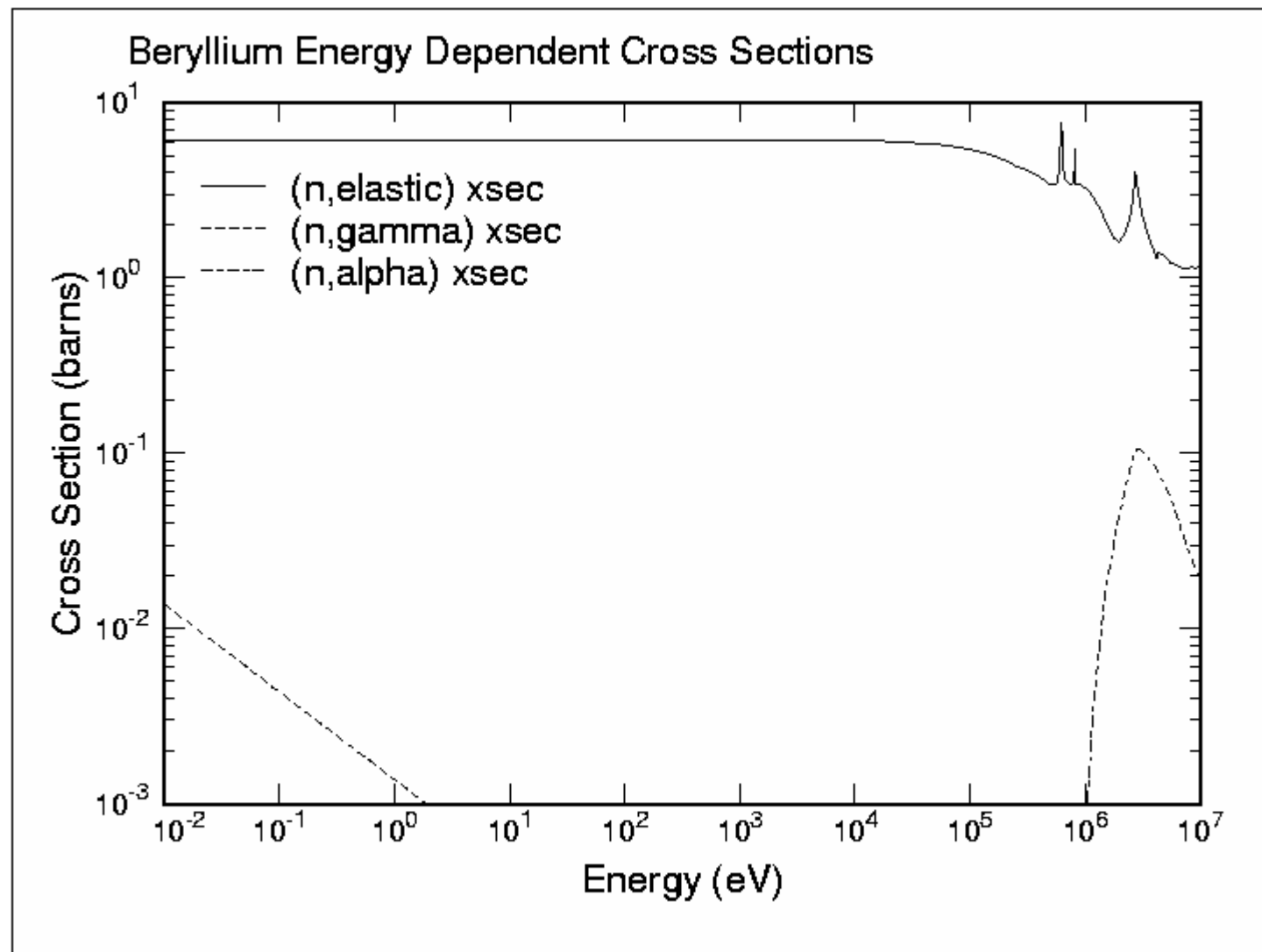
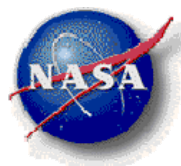
# Comparison of Hydrogen and Deuterium Cross Sections



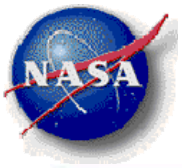






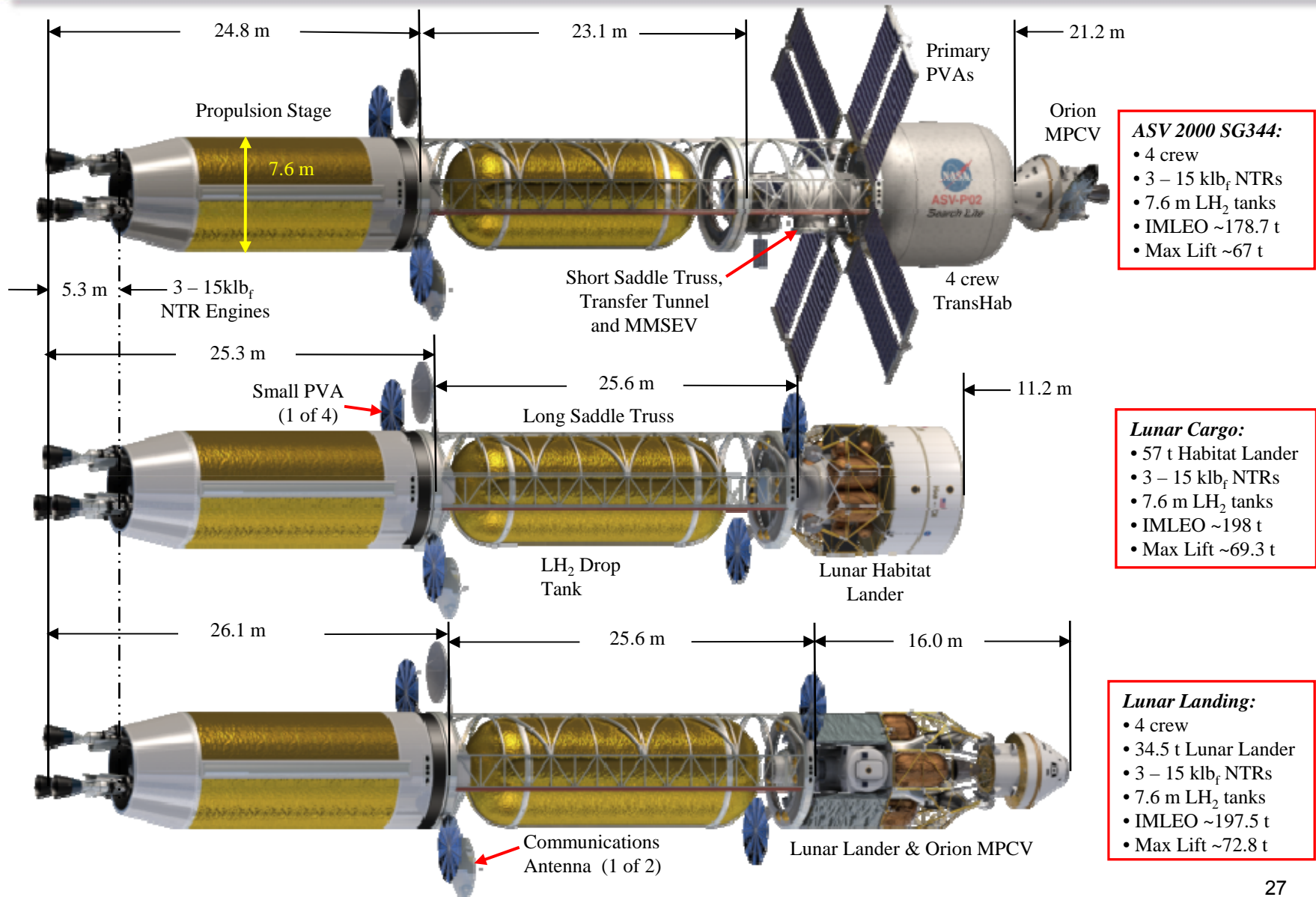


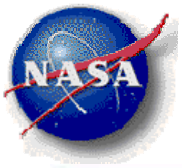




# NTR Transfer Vehicles for Reusable NEA, Lunar Cargo and Crewed Landing Missions using ~70 t-class SLS

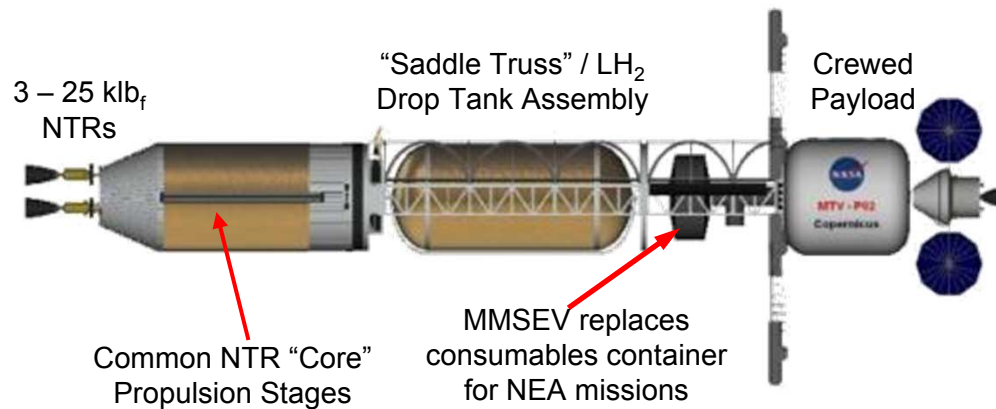
(Courtesy Stan Borowski, NASA GRC)





# Growth Paths Identified using Modular Components to Increase Vehicle LH<sub>2</sub> Capacity & Mission Applications

(Courtesy Stan Borowski, NASA GRC)



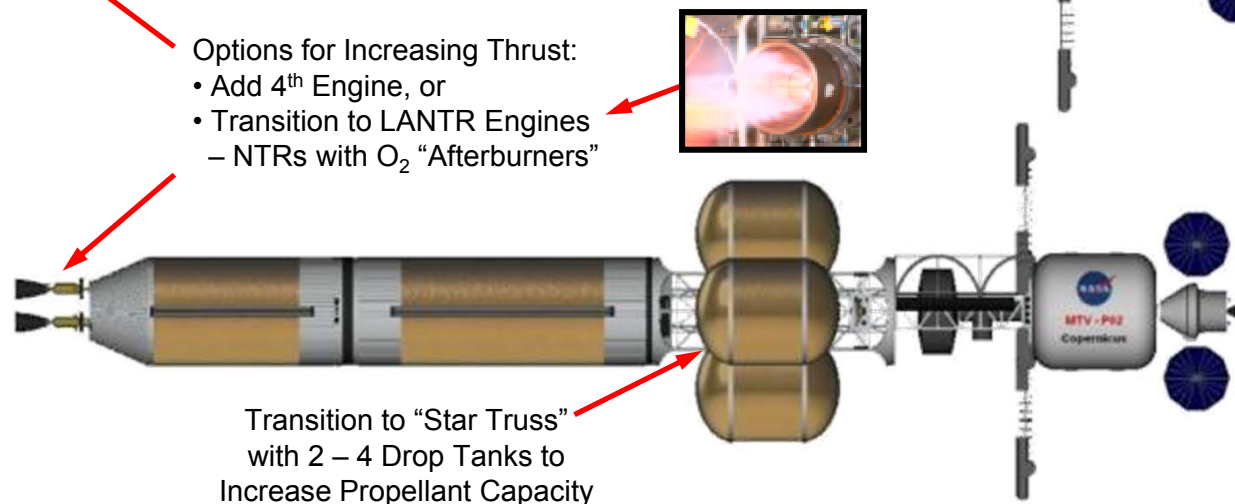
## **Configuration 1 Applications:**

- Fast Conjunction Mars Landing Missions – Expendable
- “1-yr” Round Trip to Large NEAs 1991 JW (2027) and Apophis (2028) – Reusable
- Propulsion Stage & Saddle Truss / Drop Tank Assembly can also be used as:
  - Earth Return Vehicle (ERV) / propellant tanker in “Split Mars Mission” Mode – Expendable
  - Cargo Transfer Vehicle supporting a Lunar Base – Reusable



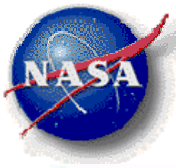
## **Configuration 2 Applications:**

- Fast Conjunction Mars Landing Missions – Reusable
- 2033 Mars Orbital Mission 545 Day Round Trip Time with 60 Days at Mars – Expendable
- Cargo & Crew Delivery to Lunar Base – Reusable



## **Configuration 3 Applications:**

- Fast Conjunction Mars Landing Missions – Reusable or Expendable
- 2033 Mars Orbital Mission 545 Day Round Trip Time with 60 Days at Mars – Reusable
- Some LEO Assembly Required – Attachment of Drop Tanks
- Additional HLV Launches



# Notional NCPS Mission -- 2033 600 day Mars Piloted Stack Core Stage, In-line Tank, & Star Truss w/ (2) LH<sub>2</sub> Drop Tanks (Courtesy Stan Borowski, NASA GRC)



## Design Constraints / Parameters:

- # Engines / Type: 3 / NERVA-derived
- Engine Thrust: 25.1 klbf (Pewee-class)
- Propellant: LH2
- Specific Impulse, Isp: 900 sec
- Cooldown LH2: 3%
- Tank Material: Aluminum-Lithium
- Tank Ullage: 3%
- Tank Trap Residuals: 2%
- Truss Material: Graphite Epoxy Composite
- RCS Propellants: NTO / MMH
- # RCS Thruster Isp: 335 sec (AMBR Isp)
- Passive TPS: 1" SOFI + 60 layer MLI
- Active CFM: ZBO Brayton Cryo-cooler
- I/F Structure: Stage / Truss Docking Adaptor w/ Fluid Transfer

## Mission Constraints / Parameters:

- 6 Crew
- Outbound time: 183 days (nom.)
- Stay time: 60 days (nom.)
- Return time: 357 days (nom.)
- 1% Performance Margin on all burns
- TMI Gravity Losses: 265 m/s total, f(T/W<sub>0</sub>)
- Pre-mission RCS ΔVs: 181 m/s (4 burns/stage)
- RCS MidCrS. Cor. ΔVs: 65 m/s (in & outbnd)
- Jettison Both Drop Tanks After TMI-1
- Jettison Tunnel, Can & Waste Prior to TEI

	Inline	(2) drop payload	core
Power Level (kW)	5.25	44.75	7.07
Tank Diameter (m)	8.90	8.90	8.90
Tank Length (m)	19.30	13.58	17.10
Truss length (m)		19	12
Liquid LH2	72.18	96.29	62.90
Total Foodstores			8.01
6 Crew			0.79
Dry weight	17.67	19.30	36.41
TransHab+Crew Science			34.649
Samples			0.25
CEV			10.10
Total Launch Element Mass (mt)	100.50	121.48	67.93
RCS Total Propellant	18.66		
Total Launched Mass	391.84	mt	

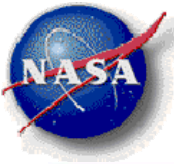
## NTP Transfer Vehicle Description:

NTP system consists of 3 elements: 1) core propulsion stage, 2) in-line tank, and 3) integrated star truss and dual drop tank assembly that connects the propulsion stack to the crewed payload element for Mars 2033 mission. Each 100t element is delivered on an SLS LV (178.35.01, 10m O.D.x 25.2 m cyl. § ) to LEO -50 x 220 nmi, then onboard RCS provides circ burn to 407 km orbit. The core stage uses three NERVA-derived 25.1 klbf engines. It also includes RCS, avionics, power, long-duration CFM hardware (e.g., COLDEST design, ZBO cryo-coolers) and AR&D capability. The star truss uses Gr/Ep composite material & the LH2 drop tanks use a passive TPS. Interface structure includes fluid transfer, electrical, and communications lines.

	ΔV (m/s)	Burn Time (min)
1st perigee TMI + g-loss	2380	39.4
2nd perigee TMI	1445	17.8
MOC	1470	15
TEI	3080	23.5
	8375	95.7

## Notional Example of Human Mars Mission





# W/VO<sub>2</sub> CERMET Fuel Element Fabrication: 7 Channel Element with Depleted Uranium



Above left/right: 7 channel W-VO<sub>2</sub> FE during HIP process

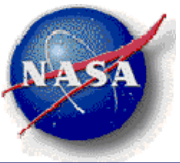


Left & above: LANL sample post fill and closeout prior to shipping



Above/Below: 7 channel WVO<sub>2</sub> fuel element post HIP and cross sections



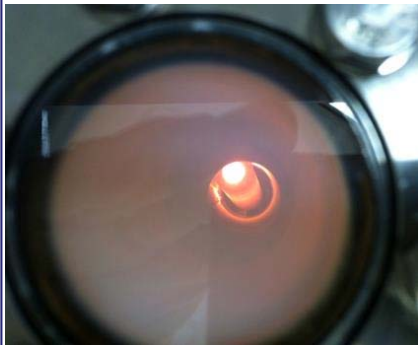


# Short, 7 Channel W/ $\text{UO}_2$ Element Fabricated and Tested in Compact Fuel Element Environmental Tester (CFEET)

## CFEET System 50 kW Buildup & Checkout



Completed CFEET system. Ready for W- $\text{UO}_2$  and  $\text{H}_2$  testing

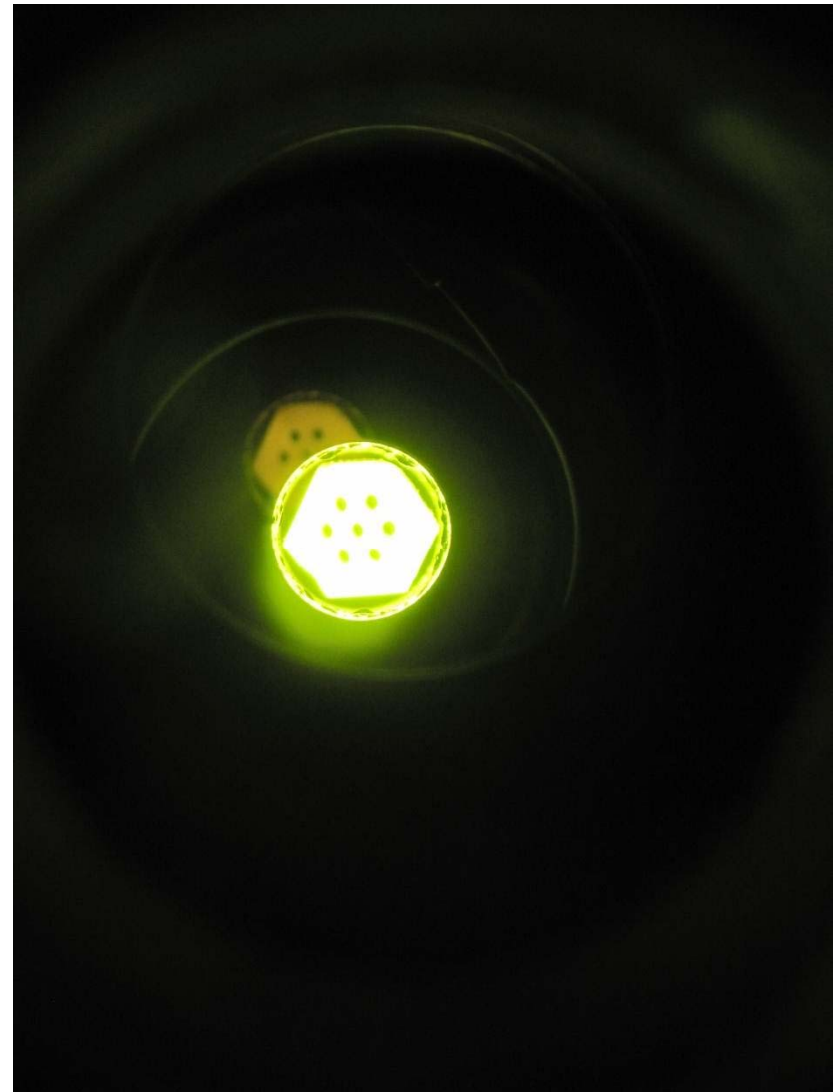


Left: View looking down into the CFEET chamber during shakeout run 1. BN insulator and bright orange sample inside

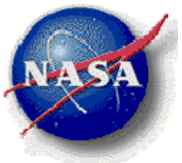


Above/left: Pure W sample post shakeout run 2. Sample reached melting point (3695K) and was held in place by the BN insulator.

## Initial Testing of Short W/ $\text{UO}_2$ Element



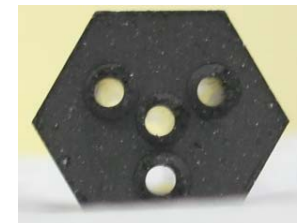




# Coated Graphite Composite Development (ORNL)



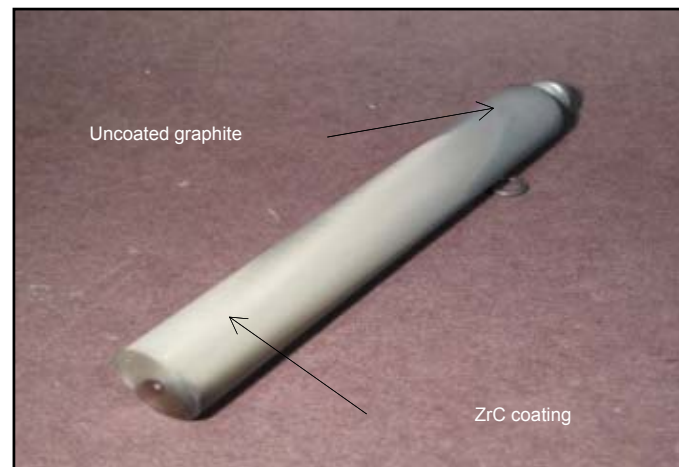
**Above: Members of Oak Ridge National Laboratory fuels team with the graphite extruder; Left: Graphite extruder with vent lines installed for DU capability**



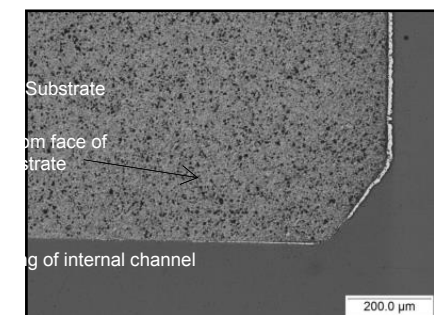
**Above and Left: Extrusion samples using carbon-matrix/Ha blend .75" across flats, .125" coolant channels**



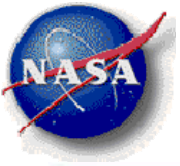
**Right: Layoff base / Graphite insert**



**Above: Test Piece highlighting ZrC Coating  
Right: Coating primarily on external surface**







# Nuclear Thermal Rocket Element Environmental Simulator (NTREES)



NTREES Phase 1 50kW (2011)



NTREES Phase 2 – 1MW Upgrade (2014)



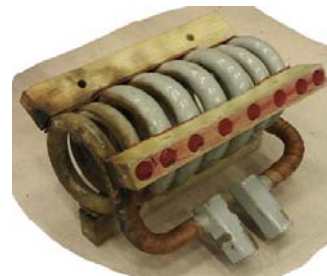
New Cooling Water System now provides 2 separate systems that cool induction coil and power feedthrough, induction heater and  $H_2N_2$  mixer respectively

## General Description:

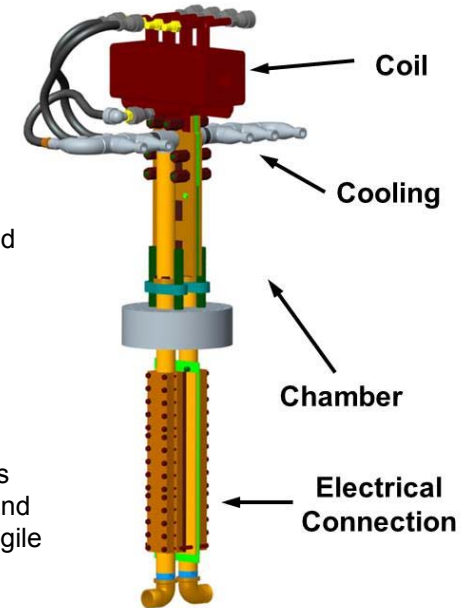
- Water cooled ASME coded test vessel rated for 1100 psi
- $GN_2$  (facility) and  $GH_2$  (trailer) gas supply systems
- Vent system (combined  $GN_2/GH_2$  flow)
- 1.2 MW RF power supply with new inductive coil
- Water cooling system (test chamber, exhaust mixer and RF system)
- Control & Data Acquisition implemented via LabVIEW program
- Extensive  $H_2$  leak detection system and  $O_2$  monitoring system
- Data acquisition system consists of a pyrometer suite for axial temperature measurements and a mass spectrometer
- “Fail Safe” design



New Coil is Heavily Insulated and Rugged

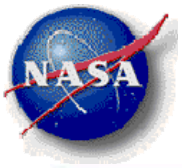


Old Coil was Uninsulated and Somewhat Fragile



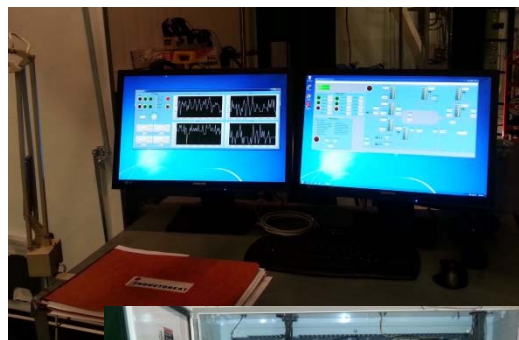
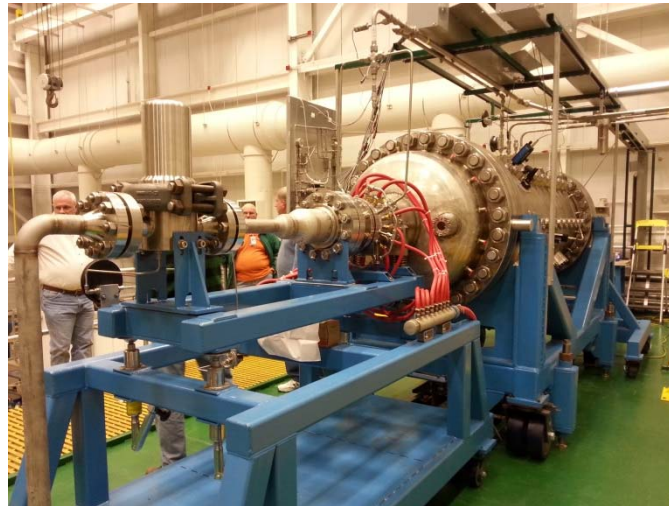
Coil and Feedthrough Assembly



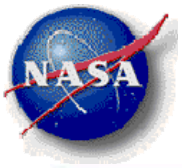


# NTREES 1 MW Operational Readiness Inspection

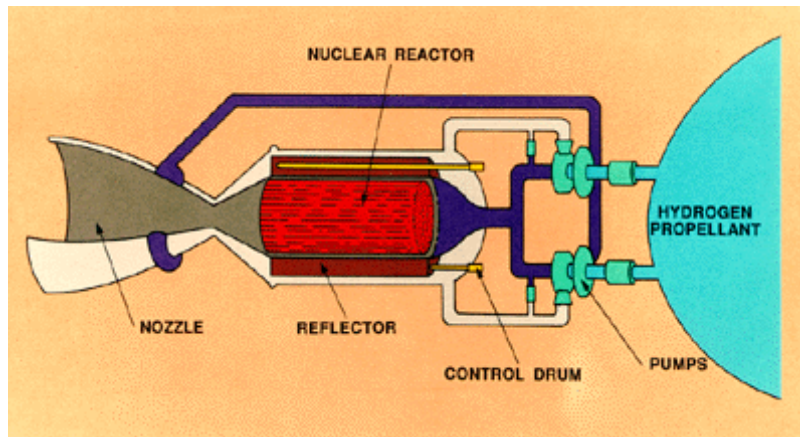
NTREES Walk-thru for ORI Board: 1/30/14



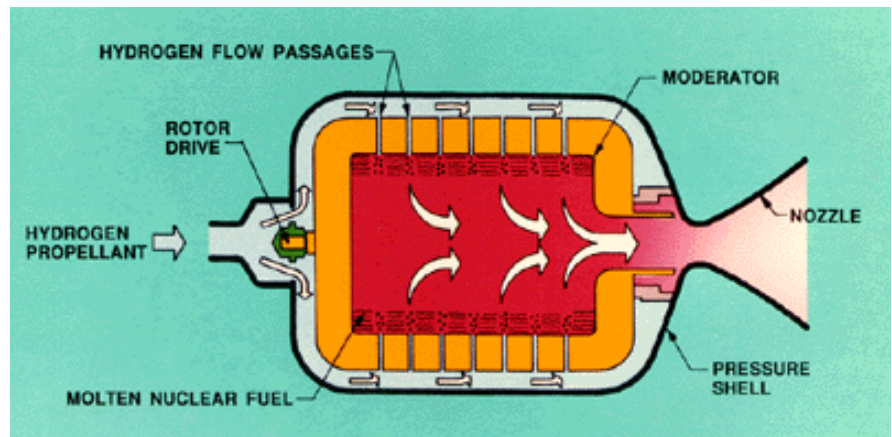




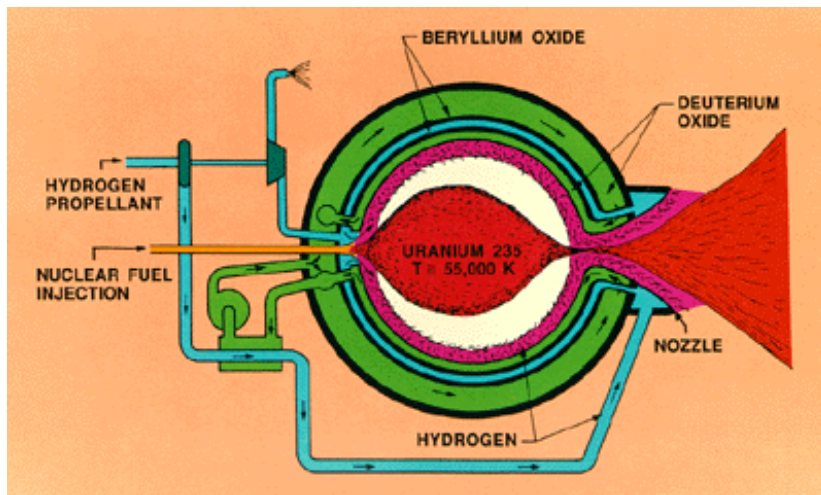
# Proposed Types of Nuclear Thermal Propulsion



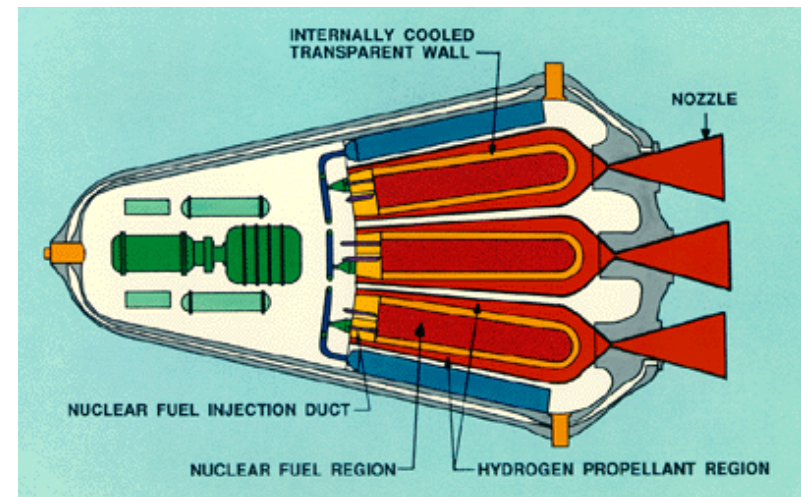
SOLID CORE NUCLEAR ROCKET



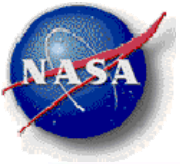
LIQUID CORE NUCLEAR ROCKET



Open-Cycle Gas Core Nuclear Rocket



Closed-Cycle Gas Core Nuclear Rocket

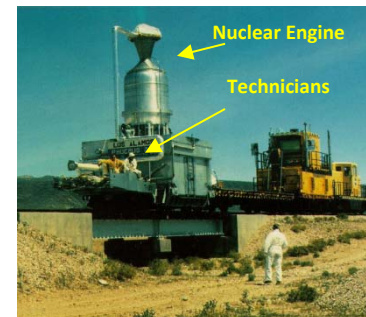


# NTP Facts



- The volume of a toy marble could contain the mass of uranium providing the NTP energy for the entire Mars Mission

- Standing next to an NTP engine before launch for one year is less radiation than diagnostic x-rays



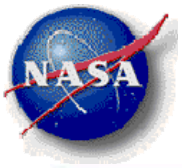
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1 Banana = 0.01 mrem

- NTP ground test regulations allow annual public dose to be 25% of what comes from all annual food you eat (e.g., bananas, potatoes, etc.), or 20 hours of plane flight



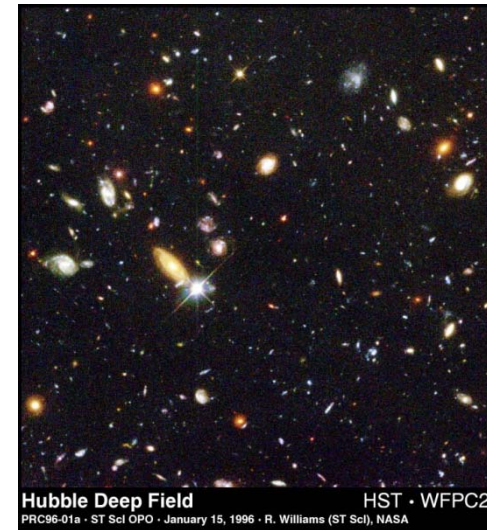
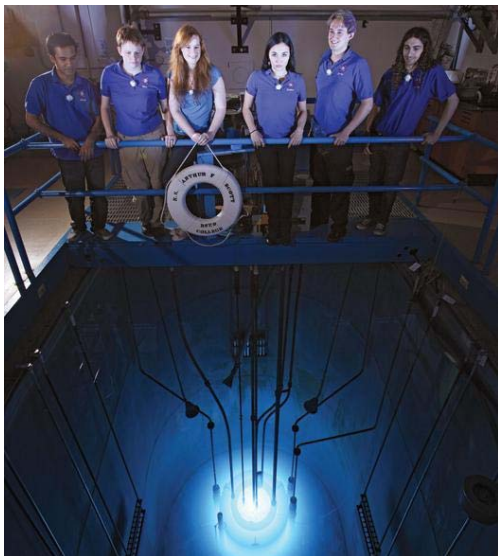


## NTP Facts (Cont'd)

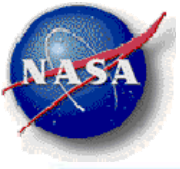


- Crews of nuclear submarines have lower radiation exposure than the general public above the water

- Using NTP for faster trip times to Mars exposes the astronauts to less galactic cosmic radiation



- NTP reactor fission products from the entire Mars mission is about equal to products formed after ~two weeks of runtime from a 10 MW college reactor



## NTP Facts (Cont'd)

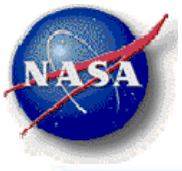


- Using NTP saves up to 4 SLS launches for a human to mars mission and saves \$B's, shortens total launch schedule, and increases chances of mission success

- NERVA prototype flight engine was ready to be fabricated based on successful NTP ground test demonstrations in 1960's. Current TRL for new fuel ~4



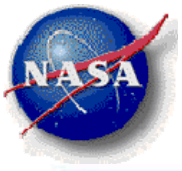
- Low enriched uranium (LEU) design has much lower security costs/risks



## Deaths by TeraWatt Hours (TWh) \*

Energy Source	Death Rate (per TWh)	Percent - World Energy /Electricity
Coal (electricity, heating, cooking)	100	26% / 50%
Coal (electricity -world average)	60	26% / 50%
Coal (electricity, heating, cooking) - China	170	
Coal (electricity) - China	90	
Coal - USA	15	
Oil	36	36%
Natural Gas	4	21%
Biofuel / Biomass	12	
Peat	12	
Solar (rooftop)	0.44	0.2% of world energy for all solar
Wind	0.15	1.6%
Hydro	0.10 (Europe death rate)	2.2%
Hydro (world including Banqiao dam failure)	1.4 (About 2500 TWh/yr and 171,000 Banquo dead)	
Nuclear	0.04	5.9%

60% for coal for electricity, cooking and heating in China. Pollution is 30% from coal power plants in China for the particulates and 66% for sulfur dioxide. Mining accidents, transportation accidents are mostly from coal for electricity.



# Nuclear Energy Myths

## Top Ten Nuclear Energy Myths

(Source: the American Nuclear Society)

### # 1: Americans get most of their yearly radiation dose from nuclear power plants

Truth: We are surrounded by naturally occurring radiation. Only .005% of the average American's yearly dose comes from nuclear power, 100 times less than we get from coal<sup>1</sup>, 200 times less than a cross country flight, and about the same as eating one banana per year.<sup>2</sup>

### # 2: A nuclear reactor can explode like a nuclear bomb

Truth: It is impossible for a reactor to explode like a nuclear weapon; nuclear weapons contain very special materials in very particular configurations, neither of which are present in a nuclear reactor.

### #3: Nuclear energy is bad for the environment.

Truth: Nuclear reactors emit no greenhouse gases during operation. Over their full lifetimes, they result in comparable emissions to renewable forms of energy such as wind and solar.<sup>3</sup> Nuclear energy requires less land use than most other forms of energy.

### #4: Nuclear energy is not safe.

Truth: Nuclear energy is as safe – or safer – than any other form of energy available. No member of the public has ever been injured or killed in the entire 50 year history of commercial nuclear power in the U.S. In, fact, recent studies have shown that it is safer to work in a nuclear power plant than an office.<sup>4</sup>

### #5: There is no solution for huge amounts of nuclear waste being generated.

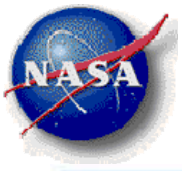
Truth: All of the nuclear fuel generated in every nuclear plant in the past 50 years would fit in a football field to a depth of less than ten yards, and 96% of this 'waste' can be recycled.<sup>5</sup> Used fuel is currently being safely stored. The U.S. National Academy of Sciences and the equivalent scientific advisory panels in every major country support geological disposal of such wastes as the preferred safe method for their ultimate disposal.<sup>6</sup>

1. National Council on Rad Protection and Measurements No. 92 and 95  
2. CDR Handbook on Radiation Measurement and Protection  
3. P.J. Meier, "Life-Cycle Assessment of Electricity Generation Systems and Applications for Climate Change Policy Analysis, 2002"

<http://www.ans.org/pi/resources/myths/docs/myths.pdf>

4. Nuclear Energy Institute (<http://www.nei.org>)  
5. K.S. Krane, *Introductory Nuclear Physics*, John Wiley and Sons, 1988  
6. *Progress Towards Geologic Disposal of Radioactive Waste: Where Do we Stand?* Nuclear Energy Agency, OECD report, 1999 (<http://www.nea.fr/rwm/reports/1999/progress.pdf>)





## Nuclear Energy Myths, continued

### Top Ten Nuclear Energy Myths

#### # 6: Most Americans Don't Support Nuclear Power

Truth: The NEI reports (Feb. 2013) that in a national telephone survey of 1,000 U.S. adults, 68 percent said they favor nuclear energy, up from 65 percent in September 2012, while 29 percent opposed. Those strongly favoring nuclear energy outweigh those strongly opposed by more than a two-to-one ratio, 29 percent versus 13 percent.

#### # 7: An American "Chernobyl" would kill millions of people.

Truth: A Chernobyl –type accident could not have happened outside of the Soviet Union because this type of reactor was never built or operated here. The known fatalities during the Chernobyl accident were mostly first responders.<sup>8</sup> Of the people known to have received a high radiation dose, the increase in cancer incidence is too small to measure due to other causes of cancer such as air pollution and tobacco use.

#### #8: Nuclear waste cannot be safely transported.

Truth: Used Fuel is being safely shipped by truck, rail, and cargo ship today. To date, thousands of shipments have been transported with no leaks or cracks of the specially designed casks.<sup>9</sup>

#### #9: Used nuclear fuel is deadly for 10,000 years.

Truth: Used nuclear fuel can be recycled to make new fuel and byproducts.<sup>10</sup> Most of the waste from this process will require a storage time of less than 300 years. Finally, less than 1% is radioactive for 10,000 years. This portion is not much more radioactive than some things found in nature, and can be easily shielded to protect humans and wildlife.

#### #10: Nuclear energy can't reduce our dependence on foreign oil.

Truth: Nuclear generated electricity powers electric trains and subway cars as well as autos today. It has also been used in propelling ships for more than 50 years. That use can be increased since it has been restricted by unofficial policy to military vessels and ice-breakers. In the near term, nuclear power can provide electricity for expanded mass-transit and plug-in hybrid cars. Small modular reactors can provide power to islands like Hawaii, Puerto Rico, Nantucket and Guam that run their electrical grids on imported oil. In the longer-term, nuclear power can directly reduce our dependence on foreign oil by producing hydrogen for use in fuel cells and synthetic liquid fuels.

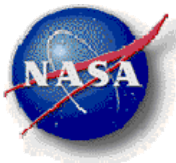
7. Perspectives on Public Opinion, NEI publication, June 2008

8. Chernobyl Forum reports 20 year findings, offers recommendations, Nuclear News, Oct-05

9. DOE Fact Sheet (<http://ocrwm.doe.gov/factsheets/doeymp0500.shtml>)

10. K.S. Krane, *Introductory Nuclear Physics*, John Wiley and Sons, 1988

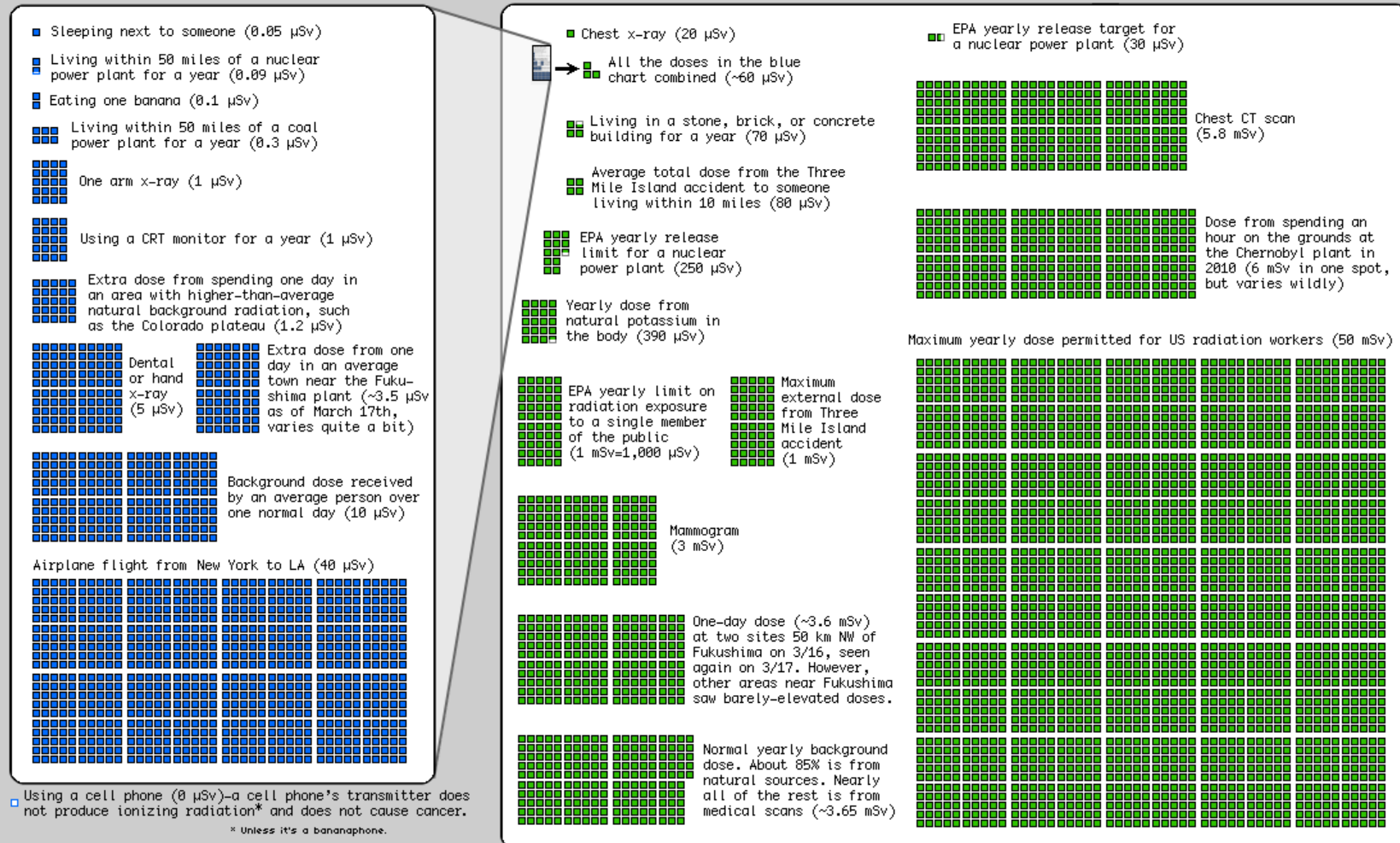
\*Source: <http://www.ans.org/pi/resources/myths/docs/myths.pdf>

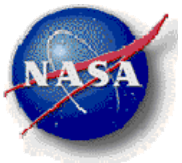


# Radiation Dose Chart

## Radiation Dose Chart

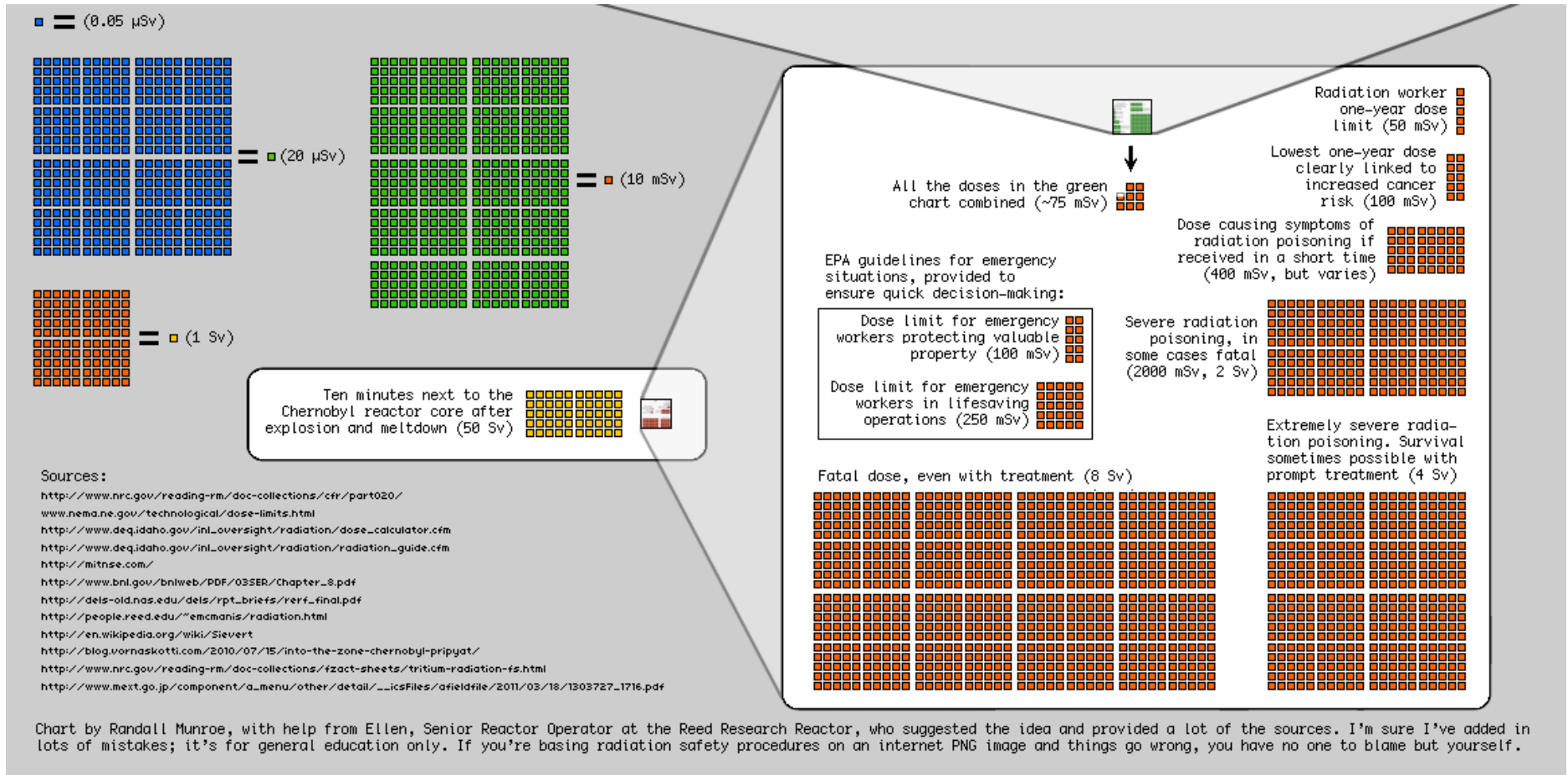
This is a chart of the ionizing radiation dose a person can absorb from various sources. The unit for absorbed dose is "sievert" (Sv), and measures the effect a dose of radiation will have on the cells of the body. One sievert (all at once) will make you sick, and too many more will kill you, but we safely absorb small amounts of natural radiation daily. Note: The same number of sieverts absorbed in a shorter time will generally cause more damage, but your cumulative long-term dose plays a big role in things like cancer risk.



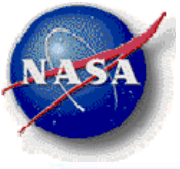


# Radiation Dose Chart (Cont'd)

Everything from previous page grouped here



1 Sv=100 rem



## Future Plans / Path Forward

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- Space fission power and propulsion are game changing technologies for space exploration
- The NASA Nuclear Thermal Propulsion (NTP) project has 1 to 3 years to demonstrate the viability and affordability of NTP
- Participation is encouraged. Please feel free to contact the NTP project with interest or ideas ([michael.houts@nasa.gov](mailto:michael.houts@nasa.gov))